THE

JOURNAL OF GEOLOGY

APRIL–MAY, 1898

CHEMICAL AND MINERAL RELATIONSHIPS IN IGNEOUS ROCKS.

THE attempt to correlate the mineral composition of igneous rocks with the chemical composition of their magmas, that is, of each rock as a whole, is rendered difficult by the chemical character of the rock-making minerals themselves, and by the fact that no fixed association of minerals necessarily results from the crystallization of an igneous rock magma, the association in a given case being affected to a greater or less extent by the physical conditions attending the solidification of the magma.

The pyrogenetic rock-making minerals are mostly silicates of several elements which may enter in different proportions into the composition of distinct minerals; so that the chemical difference between a number of these minerals lies in the proportions of their chemical components rather than in the kinds. Among the more important rock-making minerals, including the chief silicates, together with quartz and magnetite, there is no element found only in one mineral. Each constituent may enter several of them. Nevertheless there are limitations to the kinds of elements constituting certain minerals, as well as more or less definite proportions to their amounts in each case. But it is to be remembered that with the exception of quartz none of them has an absolutely fixed composition, but each belongs to an isomorphous or morphotropic series, that is, represents a more or less variable mixed salt or crystal. Variations in the chemical constituents of rock magmas will affect the chemical composi-

tion of several minerals in any case, as well as the relative proportions of all the minerals constituting the rock.

The relations between the minerals crystallized from a rock magma and the physical conditions attending its solidification have been scarcely more than recognized in a general way, though many examples have become well known. But enough has already been learned to warrant the conclusion that the attendant physical conditions exert a definite control over the grouping of the chemical elements in the molten magma, whereby the kind and character of the minerals crystallizing from it are affected. And it may be confidently predicted that careful comparison of the chemical composition of rocks with their exact mineral composition and texture, and with their mode of occurrence as geological bodies, will eventually lead to the discovery of these relationships.

Realizing the difficulties in the way of a complete correlation of the mineral and chemical composition of igneous rocks, and the limitations of our present knowledge both as to the relationships just mentioned, and as to the actual chemical composition of many rock-making minerals, it may still be possible to make a beginning of the correlation by attempting to state certain relationships between the theoretical molecules of the chief rock-making minerals and the chemical composition of igneous rock magmas.

Composition of the rock-making minerals.—Owing to the complexity of even this preliminary correlation, it is advisable to consider only the more important rock-making minerals, leaving the less frequent ones for future elaboration of the discussion. The former may be grouped as follows: Quartz, the feldspathic minerals: the feldspars proper, with leucite, nephelite and the sodalites; muscovite, forming a link between feldspathoid minerals and ferromagnesian minerals; biotite and the other ferromagnesian minerals: olivines, pyroxenes, amphiboles; besides magnetite. Minerals necessary to a fuller discussion are melilite, garnet, titanite, perofskite, apatite, zircon, and others.

The chemical composition of each of these minerals, or groups

of minerals, may be expressed in the simplest form, as in the following list, first by the empyrical formulas, second by the dualistic, the convenience of the latter being apparent when comparison is made with the chemical composition of the rocks, as expressed in the usual statement of analyses.

Quartz,	SiO_2	SiO_2
Orthoclase,	$KAlSi_3O_8$	$K_2O.Al_2O_3.6SiO_2$
Soda-orthoclase, Soda-microline,	$(K,Na)AlSi_3O_8$	$(K,Na)_2O.Al_2O_3.6SiO_2$
Albite,	$NaAlSi_3O_8$	$Na_2O.Al_2O_3.6SiO_2$
Oligoclase, Andesine, Labradorite,	$\left\{\begin{matrix} m\,(NaAlSi_3O_8) \\ n\,(CaAl_2Si_2O_8) \end{matrix}\right\}$	
Anorthite,	$CaAl_2Si_2O_8$	$CaO.Al_2O_3 2SiO_2$
Leucite,	$KAlSi_2O_6$	$K_2O.Al_2O_3.4SiO_2$
Nephelite,	$\left\{\begin{matrix} KAlSi_3O_8 \\ n\,(NaAlSiO_4) \end{matrix}\right\}$	
Soda-nephelite,	$NaAlSiO_4$	$Na_2O.Al_2O_3.2SiO_2$
Sodalite,	$Na_4(AlCl)Al_2Si_3O_{12}$	$3[Na_2O.Al_2O_3.2SiO_2]+2NaCl$
Hauynite,	$Na_2Ca(NaSO_4.Al)Al_2Si_3O_{12}$	$3[Na_2O.Al_2O_3.2SiO_2]+2CaSO_4$
Nosite,	$Na_4(NaSO_4.Al)Al_2Si_3O_{12}$	$3[Na_2O.Al_2O_3.2SiO_2]+2NaSO_4$
Muscovite	$KH_2Al_3Si_3O_{12}$	$(K,H)_2O.Al_2O_3.2SiO_2$
Biotite,	$(H,K)_2(Mg,Fe)_2(Al,Fe)_2(SiO_4)_3$ or $\left\{\begin{matrix} 2[(H,K)(Al,Fe)SiO_4] \\ (Mg,Fe)_2SiO_4 \end{matrix}\right\}$	$2[(H,K)_2O.(Al,Fe)_2O_3.2SiO_2]$ $2(Mg,Fe)O.SiO_2$
Olivine,	$(Mg,Fe)_2SiO_4$	$2(Mg,Fe)O.SiO_2$
Pyroxenes		
Enstatite,	$Mg_2Si_2O_6$	$MgO.SiO_2$
Hypersthene,	$(Mg,Fe)_2Si_2O_6$	$(Mg,Fe)O.SiO_2$
Diopside,	$CaMgSi_2O_6$	$CaO.MgO.2SiO_2$
Salite,	$Ca(Mg,Fe)Si_2O_6$	$CaO.(Mg,Fe)O.2SiO_2$
Augite,	$\left\{\begin{matrix} Ca(Mg,Fe)Si_2O_6 \\ (Mg,Fe)(Al,Fe)_2SiO_6 \end{matrix}\right\}$	$\left\{\begin{matrix} CaO(Mg,Fe)O.2SiO_2 \\ (Mg,Fe)O.(Al,Fe)_2O_3.SiO_2 \end{matrix}\right\}$
Acmite,	$NaFeSi_2O_6$	$Na_2O.Fe_2O_3.4SiO_2$
Amphiboles		
Hornblende,	$\left\{\begin{matrix} Ca(Mg,Fe)_3Si_4O_{12} \\ (Mg,Fe)_2(Al,Fe)_4Si_2O_{12} \\ Na_2Al_2Si_4O_{12} \end{matrix}\right\}$	$\left\{\begin{matrix} CaO.3(Mg,Fe)O.4SiO_2 \\ (Mg,Fe)O.(Al,Fe)_2O_3.SiO_2 \\ Na_2O.Al_2O_3.4SiO_2 \end{matrix}\right\}$
Arfvedsonite,	$\left\{\begin{matrix} (Na_2,Ca,Fe)_4Si_4O_{12} \\ (Ca,Mg)_2(Al,Fe)_4Si_2O_{12} \end{matrix}\right\}$	$\left\{\begin{matrix} (Na_2,Ca,Fe)O.SiO_2 \\ (Ca,Mg)O.(Al,Fe)_2O_3.SiO_2 \end{matrix}\right\}$
Riebeckite,	$\left\{\begin{matrix} Na_2Fe_2Si_4O_{12} \\ FeSiO_3 \end{matrix}\right\}$	$\left\{\begin{matrix} Na_2O.Fe_2O_3.4SiO_2 \\ FeO.SiO_2 \end{matrix}\right\}$
Magnetite,	Fe_3O_4	

From this it will appear into how many different molecules any chemical element many enter. In order to simplify the

problem further, the several kinds of molecules may be presented in the following manner:

Elements	Kinds of molecules		Kinds of minerals
K, Na, Al,	$(K,Na)_2O:AlO_3:SiO_2$	1:1:6	orthoclase, albite
		1:1:4	leucite (amphibole)
		1:1:2	nephelite, sodalite (with excess of Na.)
	$(K,H)_2O:Al_2O_3:SiO_2$	1:1:2	muscovite ($Al_2O_3 > K_2O$)
K, Na, Al, Fe,	$(K,H)_2O:(Al,Fe)_2O_3:SiO_2$	1:1:2	mica (biotite)
Na, Fe,	$Na_2O:Fe_2O_3:SiO_2$	1:1:4	acmite, riebeckite
Na, Fe, Ca,	$(Na_2,Ca,Fe)O.SiO_2$		arfvedsonite
Ca, Al,	$(CaO:Al_2O_3:SiO_2$	1:1:2	anorthite
Ca, Mg, Fe,	$CaO.(Mg,Fe)O.2SiO_2$		pyroxene
	$CaO.3(Mg,Fe)O.4SiO_2$		amphibole
Mg, Fe,	$(Mg,Fe)O.SiO_2$		pyroxene
			olivine, mica
Mg, Fe, Al,	$(Mg,Fe)O.(Al,Fe)_2O_3.SiO_2$		pyroxene, amphibole

The alkalis combine with an equal number of molecules of alumina in the feldspathic minerals (except sodalites). These are polysilicates, metasilicates and orthosilicates; also in one of the amphibole molecules; while in muscovite part of the potassium is replaced by hydrogen. The alkalis with hydrogen enter into an orthosilicate, mica molecule with alumina and ferric oxide in the proportion of 1:1, the potash being generally less than alumina. Soda enters into a metasilicate molecule with ferric oxide, in the acmite molecule. It combines with lime and ferrous oxide in the metasilicate, arfvedsonite molecule. Calcium oxide enters an orthosilicate molecule with alumina in proportions of 1:1.—anorthite. Calcium occurs with magnesium and iron in metasilicate molecules in pyroxenes and amphiboles, which differ in the relative proportions of CaO:(Mg, Fe)O; in the first case in the ratio 1:1; in the second, 1:3. Magnesium and ferrous iron usually occur together in variable proportions, either in a metasilicate molecule with calcium in monoclinic pyroxenes and amphiboles, or without calcium in metasilicate molecules in orthorhombic pyroxenes, or in orthosilicate molecules in olivine and mica. They combine with aluminium and ferric iron in a subsilicate molecule in pyroxenes and

amphiboles. Magnesium may occur without iron in metasilicate molecules, in diopside with calcium, and in enstatite without calcium. The alkali-alumina silicates may be polysilicates, metasilicates or orthosilicates. The ferromagnesian silicates may be metasilicates, orthosilicates or subsilicates. Iron may occur uncombined with silica in the form of magnetite, and silica may occur uncombined with other elements in the form of quartz or tridymite.

Preliminary correlation.— Some of the more evident relationships between the pyrogenetic minerals in igneous rocks and the chemical composition of the magma have been stated in a previous article in this volume.[1] They are : the usual occurrence of quartz with the polysilicate feldspars, and its non-occurrence with the meta- and orthosilicate feldspathic minerals: leucite, nephelite and sodalite; also the relation between these and the percentage of silica in the rock — the highest of these silicates always forming which is possible with the available silica in the magma. Another law seems to be that the alkalis control an equal amount of alumina, forming alkali-feldspathic molecules, and that aluminium in excess of this may combine with calcium to form anorthite molecules, or with magnesium and iron to enter pyroxene and amphibole molecules. Soda does not seem to unite with ferric oxide to enter pyroxenes or amphiboles in any considerable amount unless it is in excess of alumina. The metasilicate, orthorhombic pyroxenes, hypersthene and enstatite, usually occur in the more siliceous rocks instead of the orthosilicate, olivine, which usually occurs in the less siliceous rocks. But this is not an invariable rule, and olivine occasionally occurs in the more siliceous rocks (dacite) and not unfrequently in the presence of quartz. The orthosilicate, mica, commonly occurs in highly siliceous rocks together with quartz; pyrogenetic muscovite exclusively so. Biotite also occurs in rocks low in silica. Its range of occurrence bears no fixed relation to the percentage of silica in the rock. Magnetite occurs in rocks of all degrees of siliceousness and is not directly dependent on the

[1] On Rock Classification, Jour. Geol., Vol. VI, pp. 96–98.

amount of silica in the magma. It frequently occurs in association with quartz or tridymite. It is a general law that the ferromagnesian minerals become more abundant as the quartz and feldspathic minerals become less abundant.

A method of correlating the chemical and mineral composition of igneous rocks on a basis of the silica percentage and of the relative amounts of alkali in each case has been presented in the article in this volume [1] already cited. It is now proposed, without repeating what has been stated in that connection, to discuss in greater detail some of the relations between the mineral and chemical constituents of igneous rocks by making use of similar diagrams. In order to do this it will be necessary to start with the simplest assumptions, and those that appear to rest on the more general laws. Having obtained some of the simpler conceptions, more complex ones may be attempted with less danger of confusion.

It is possible to obtain an idea of the range of quartz and of leucite, nephelite and sodalite in igneous rocks by considering the most favorable cases for their occurrence, and afterwards the conditions that would modify their production. In order to render the discussion as simple as possible it is advisable to consider the extreme cases in which the alkali is either wholly soda or wholly potash. In Diagram 1 the black spots represent the rocks in which the soda is more than twice as great as potash, and the red spots those in which the potash is greater than soda. They correspond to the spots on Diagrams 2 and 4, Plates I and II of this volume. They are introduced to aid the imagination. The significance of the lines is explained in the text. For the phrase "the analysis or analyses of rocks" in the discussion of the diagrams the phrase "the rock or the rocks," will be substituted, it being understood that only the chemical attributes of the rocks are under discussion.

I. Let us first postulate the case of magmas whose *alkali is wholly soda*, and in which the *molecules of alumina are always in equal proportions to those of soda*. Then with no other constituent

[1] Loc. cit., pp. 98–103.

except varying percentages of silica the resulting rocks if wholly crystallized would consist of orthosilcate of sodium and aluminium, nephelite; this with polysilicate of the same elements, albite; albite alone; or albite and quartz, according as silica is lower or higher. We may say the rocks would lie on the curved line *QAN*. The point *Q* is where pure quartz occurs; and the point *A* where pure albite occurs; and *N* where soda-nephelite occurs. Pure albite rock would occur at *A*. Any rock on the line between *A* and *N* would consist of albite and soda-nephelite in proportions varying from one extreme to the other. Any rock on the line between *A* and *Q* would consist of albite and quartz in proportions varying in the same manner.

From *A* as a point of departure let us consider what must be the composition of soda-alumina rocks not occurring on the line *QAN*. If we consider magmas with constant alkali-silica ratios, namely .166, it is evident that proceeding from *A* horizontally, as the silica percentage becomes less, the soda and alumina must also become less, consequently the sum of these constituents will not be 100, which is always the total of the percentages in any case. There must therefore be other chemical constituents besides Na_2O, Al_2O_3 and SiO_2. The same is true if we proceed from *A* vertically downwards, that is, if we consider magmas having the same silica percentage, namely 68.7, for with decreasing alkali-silica ratios there will be less soda and alumina, and the sum of Na_2O, Al_2O_3, SiO_2 will not be 100. The same will be true if we proceed in any direction from *A* below the line *QAN*.

All rocks except those occurring upon this line must contain other constituents than Na_2O, Al_2O_3, SiO_2. These may be CaO, MgO, FeO, Fe_2O_3 (potash being excluded by the initial assumption). Let us assume them to be either CaO, MgO, FeO, singly or together, and that they occur as silicates. The case of $FeO.Fe_2O_3$, magnetite, will be considered subsequently. It having been assumed that alumina is present only in proportions to satisfy soda, the possibility of the formation of an aluminous molecule with these constituents will be excluded for the

present. The silicates capable of forming from CaO, MgO and FeO are orthosilicates and metasilicates; olivine, $2(Mg,Fe)O.SiO_2$, with its theoretically possible extremes $2FeO.SiO_2$ (fayalite) and $2MgO.SiO_2$ (fosterite); orthorhombic pyroxenes, enstatite, $MgO.SiO_2$, and hypersthene, $(Mg,Fe)O.SiO_2$, and the monoclinic pyroxenes, diopside, $CaO.MgO.2SiO_2$, and salite, $CaO.(Mg,Fe)O.2SiO_2$. It is possible to introduce into the composition of a magma such as already postulated one or more of these molecules in such proportions as to make the sum of all equal to 100. But it is clear that the development of a silicate of any of these kinds in the magma would affect the distribution of the silica among the other molecules, that is, it would affect the relative porportions of albite and nephelite or of albite and quartz. It is possible to discover by simple algebra what would be the range of percentages of silica and the range of the alkali-silica ratio for a series of rocks composed wholly of albite and any one of the calcium, iron, magnesium molecules just mentioned. This range will be expressed by a curved line on the diagram extending from the point *A* to the point corresponding to the locus in the diagram of the pure molecule under consideration. Several of these lines are indicated on Diagram 1. The most extreme case, most favorable to the presence of albite is that in which it occurs in combination with $2FeO.SiO_2$, orthosilicate of iron. The range is indicated by line *AFa*, which shows the alkali-silica ratios necessary in order that a rock should consist wholly of albite and Fe_2SiO_4. Any rock occurring above this line and containing only the constituents $Na_2O = Al_2O_3$, FeO, SiO_2 would have relatively too little silica to form albite out of all the soda and alumina and would contain some nephelite. That is, all rocks of this kind occurring above the line *AFa* would carry nephelite, even those having alkali-silica ratio $= .03$, if $SiO_2 = 31$. Conversely, all rocks occurring below this line would have relatively too much silica to convert all the soda and alumina into albite and there would necessarily be quartz, if FeO alone formed an orthosilicate, which is the case in hand. Quartz would thus be a necessity in rocks with

only 35 per cent of SiO_2 when the alkali-silica ratio is less than .045. For a combination of albite and $2MgO.SiO_2$ the range is shown by the line *AFo*, and for a combination of albite and olivine, $2(Mg,Fe)O.SiO_2$, in which Mg : Fe :: 3 : 1, the range is *AOl*. From this it is seen that if orthosilicate of magnesium accompanies that of iron the nephelite limit will advance toward the left, that is, in the direction of higher silica percentages, and the quartz limit will recede in the same direction.

In case iron and calcium or magnesium occur as metasilicates the range of possible combinations of these with albite is shown by the lines *AF*, *AC*, *AM*. If magnesium and iron occur together in equal proportions, as in some hypersthene, the line nearly coincides with *AC*. So also if the metasilicate has the composition $CaMgFeSi_3O_9$, or $Ca_2MgFeSi_4O_{12}$ (a diopside) or $Ca_2Fe_3Mg_3Si_8O_{24}$ (actinolite molecule in amphibole) the range would coincide with the same line. An increase of magnesium would move the line to the left toward *AM*. The range of positions for diopside is indicated by the bracket in the diagram. The range of positions for enstatite would lie to the left of this for the most part. From this it appears that rocks having soda and alumina in equal amounts together with metasilicates of iron, magnesium and calcium, if they occur to the right of the limits just described would necessarily contain nephelite, and if they occur to the left of these limits they must contain quartz. Since metasilicates are the highest silicate of these elements occurring in igneous rocks it follows that no other ferromagnesian molecule may be postulated which will appropriate more silica from the magma. Hence the most favorable case, namely that involving the highest silicate of alkali and alumina and the highest of calcium, iron, and magnesium, requires the presence of quartz in all holocrystalline rocks occurring to the left of these lines. In actual fact the three elements just named usually occur in somewhat similar proportions, so that the position of the line *AC* represents the limit of quartz in the ordinary case most favorable to its scarcity. Any combination of orthosilicate will tend to move

the quartz limit still further toward the right, in the direction of lower silica percentages. Quartz must therefore occur in rocks with lower and lower silica in proportion as the alkali-silica ratio decreases, and as lower silicate molecules are developed instead of higher silicates. The line *AC* is probably very near the highest limit of *no quartz* to be found in holocrystalline igenous rocks.

If any of the iron crystallizes as magnetite instead of combining with silica to form ortho- or metasilicates, silica will be liberated to form more albite out of nephelite, or to produce more quartz by the side of albite. The effect of the development of magnetite then is to shift the quartz-nephelite limit farther to the right, that is, toward lower silica percentages. In the case of rocks within the nephelite limit, the effect will be to decrease the nephelite and increase the albite. It may also react upon the ferromagnesian silicates when orthosilicates are present, permitting the liberated silica to convert some of the orthosilicates into metasilicates without materially affecting the relative proportions of the other constituent minerals.

In this connection attention may be called to the line *NFa*, which is the range of magmas composed wholly of nephelite and the orthosilicate of iron. It appears to be the limit toward which the highly sodic magmas tend, as may be seen in Diagram 1. Magmas low in alkalis associated with the eruptive iron ores lie beyond this boundary.

II. In order to discover the relations that would obtain for magmas in which *the alkali is wholly potash* when *alumina is present in amounts just equal to the potash*, we have to consider the range of positions for rocks corresponding to mixtures of quartz and orthoclase (potassium-aluminium polysilicate), and of orthoclase and leucite (potassium-aluminium metasilicate). This corresponds to the red line *QOL*. As already remarked in the previous paper, the lowest potassium-aluminium silicate among the feldspathoid minerals appears to be the metasilicate, leucite, and when potassium is found in rock-making nephelite it may be explained as in a metasilicate molecule mixed with the

sodium-aluminium orthosilicate. If we conduct the discussion in the same manner as in the previous case we should proceed from the point *O*, the position for a pure potash-orthoclase rock. At this point the alkali silica ratio $=.166$ and $SiO_2=64.7$. Rocks consisting of pure orthoclase and leucite will occur along the line *OL;* those composed of pure orthoclase and quartz along the line *OQ*. Rocks having an alkali-silica ratio of .166 and less than 64.7 per cent. of silica must contain some other constituents than $K_2O=Al_2O_3$ and SiO_2. The same is true for all rocks lying below the line *QOL*. The range of rocks that might consist of pure orthoclase and orthosilicate of iron is shown by the red line *OFa*, close to the corresponding line for soda magmas. All rocks occurring above this would necessarily contain leucite, all below it would contain quartz. The lines *OOl* and *OFo* represent the range for rocks consisting respectively of orthoclase and olivine, and of orthoclase and orthosilicate of magnesium. They also mark the limit of the quartz-bearing rocks of this kind on one side, and of leucite rocks on the other. The lines for rocks composed of orthoclase and metasilicates of iron, magnesium and calcium are *OF*, *OC*, *OM*. They are somewhat further from the corresponding ones for soda magmas than in the case of the orthosilicates. Comparing their positions with those of the corresponding lines for soda magmas, it is seen that the quartz limit is lower in the scale of silica percentages for potash magmas than for soda magmas. That is, other things being equal, quartz will occur in less siliceous potash rocks than in the corresponding soda rocks, the most marked differences being in rocks highest in alkalis.

The development of magnetite would have the same effect in shifting the quartz-leucite limits toward the right, that is, toward rocks with lower silica percentages as in the case of soda magmas. The line *LFa* is the range for magmas composed of leucite and orthosilicate of iron and seems to be the lowest limit for potash magmas, as stated on page 102 of this volume.

Magmas in which both soda and potash occur with equal

amounts of alumina would behave in a manner analagous to that just described for either extreme, the feldspars would be soda-potash polysilicates, with quartz or with leucite or nephelite. The lines indicating the range of combinations of feldspar and ferro-magnesian silicates would occupy positions intermediate between the corresponding lines for albite and for orthoclase. The quartz-leucite-nephelite limits would be nearly the same as before.

III. Let us now postulate the case of magmas in which the *alkalis control an equal amount of alumina* and in which *lime and additional alumina occur in the proportion of one to one* and *constitute orthosilicate, anorthite molecules*. First, let all of the alkali be soda. This case is illustrated by Diagram 2. As the relative proportions of the constituents, $Na_2O=(Al_2O_3)'$, $CaO=(Al_2O_3)''$ and SiO_2 vary, those rocks in which there is soda and no lime will consist of albite and quartz, or of albite and nephelite, and will occur along the line *QAN*, Diagram 2, as in the previous Diagram 1. All rocks occurring below this line will contain anorthite molecules in variable proportions. Pure anorthite rock will occur at the point *An*, where the alkali-silica ratio $=0$, and $SiO_2=43.2$. The range of rocks composed wholly of albite and anorthite in varying proportions will occur along the line *AAn*. They correspond to rocks each consisting of a feldspar of the albite-anorthite series. The points on this line at which particular mixtures occur, such as Ab_6An_1, Ab_3An_1, etc., are designated in the diagram. This line also indicates the range of rocks consisting wholly of soda-lime-feldspar. All rocks from magmas of this case, III, to the right of this line must contain nephelite in addition to these feldspars. All rocks to the left must contain quartz, the argument being the same as for magmas of cases I and II. Assuming that the feldspar present is always one corresponding to the particular combination of albite and anorthite molecules in the magma, we may discover the range of magmas consisting of combinations of each of these kinds of feldspar and quartz on the one hand, and of these and nephelite on the other. They are

indicated by the lines *QA*, *Qb*, . . *QAn* and *NA*, *Nb*, . . *NAn*, which also indicate the limits for magmas of this kind. None would be possible to the right of the line *NAn*, unless containing other elements than those already mentioned for this case, III.

Since within the boundaries *QNAn*, rocks may exist composed wholly of quartz and the feldspathic minerals mentioned, the presence of any ferromagnesian compound necessitates the diminution of some of the first-named constituents, and since the silica percentages and alkali-silica ratios are the coördinates by which comparisons are made, we may assume that the presence of ferromagnesian constituents affects the lime and its equivalent alumina. Let them be affected equally. The orthosilicate anorthite molecules may then be replaced in some uniform manner by non-aluminous ferromagnesian orthosilicates or metasilicates. If the anorthite molecules be replaced by orthosilicate of iron, Fe_2SiO_4, the varying results are indicated in Diagram 2. If wholly replaced by Fe_2SiO_4, the line *AFa* would represent the range of the resulting rocks composed of varying proportions of albite and Fe_2SiO_4. And the area *AFaAn* would be the range of rocks composed of varying proportions of albite and Fe_2SiO_4 and anorthite. The lines *bFa*, *cFa*, etc., indicate the ranges of rocks composed of Fe_2SiO_4 and Ab_6An_1, Fe_2SiO_4 and Ab_2An_1, etc. That is, ranges in which the character of the lime-soda feldspar is constant, but the proportions of Fe_2SiO_4 vary. The line *Ay* shows the range of rocks composed of albite, with varying amounts of anorthite and Fe_2SiO_4 in the proportion of 4 to 3. At the points *b'*, *c'*, *d'*, etc., where this line intersects the lines *bFa*, etc., the rocks would consist of Fe_2SiO_4 and the feldspars Ab_6An_1, Ab_2An_1, etc. From this it is evident that as the molecules of anorthite are replaced by ferromagnesian molecules, the feldspars in a rock of any given silica percentage and alkali-silica ratio become relatively higher in albite molecules, that is, the lines *Ob*, *Oc*, etc., would shift farther from *QA;* more sodic feldspars would occur in rocks with lower alkali-silica ratios. There would be a similar movement of the lines *Nb*, *Nc*, etc.,

away from *NA;* more sodic feldspars would be found in rocks lower in silica.

If the anorthite molecules be replaced by orthosilicates of iron, or of iron and magnesium, less silica would be required than before, and the quartz limit would shift to the right. If they were replaced by metasilicates of iron, magnesium or calcium, more silica would be required, and the quartz limit would shift to the left. If both were developed together the quartz limit might remain nearly as before. If magnetite were developed the effect on the quartz limit would be still more marked, and it would be shifted still farther in the direction of lower silica percentages.

Second, let all of the alkali be potash. Assuming that in this case there would be two distinct kinds of feldspar present, potash-orthoclase and anorthite, the range of rocks consisting wholly of these two minerals in variable proportions would lie along the red line *OAn*, Diagram 3, and the line *QOL* would be the range of rocks of this kind free from anorthite. All rocks of this kind occurring to the right of the line *OAn* must contain leucite; all those to the left must contain quartz. The effect of replacing anorthite molecules by ferromagnesian molecules would be similar to that just stated for the albite-anorthite magmas; however, orthoclase not being combined with anorthite, would remain as before except where changes in the silica affected the orthoclase molecules by reducing them to leucite. or affected the leucite molecules by raising them to orthoclase. This would occur in the neighborhood of the line *OAn*.

Third, if soda and potash were both present, other things being the same as postulated in the general statement of case III, it is evident that the range of rocks that might consist wholly of feldspars, either pure albite, pure orthoclase, or pure anorthite, or any possible mixture of these, would be within the area *AOAn*, Diagram 3. This narrow area would be the boundary between the quartz range on one side and the leucite-nephelite range on the other. The effect on the albite-anorthite feldspar, whose character would be that previously indicated if

all the alkali were soda, by the partial replacement of soda by potash would be to render it lower in the scale toward the anorthite end, so that the amount of orthoclase would be increased and the accompanying lime-soda-feldspar would be more calcic. This is indicated in Diagram 3. As potash replaces soda, the extreme limit of pure alkali-alumina silicate would shift along the line *NL* toward *L*. When they are in equal amounts the limit would be at *P*. At the same time, the range of rocks consisting wholly of anorthite, with albite and orthoclase in equal proportions, would be indicated by the line *xAn*. The points *b'*, *c'*, *d'*, etc., on it are where the lime-soda feldspar would have the value of Ab_6An_1, Ab_2An_1, Ab_1An_1, etc. The red lines connecting these points with *P* on one side and with *Q* on the other represent the range of rocks composed wholly of these particular lime-soda feldspars and leucite-nephelite on the one hand, and of these feldspars and quartz on the other. The replacement of anorthite molecules by ferromagnesian ones will have the same effect as that just stated for each extreme of alkali-lime-feldspar magmas.

IV. There remains to be discussed the modifications that would be effected in the feldspathic magmas already postulated by the introduction of ferroaluminous molecules. These may be of two kinds: ferromagnesian-ferroaluminous molecules, appearing in pyroxenes and amphiboles, with the general formula $(Mg,Fe)(Al,Fe)_2SiO_6$; and alkali-ferroaluminous molecules, occurring in mica, amphiboles, and pyroxene. Among these are molecules free from ferric iron, and others free from aluminium. They are $KH_2Al_3Si_3O_{12}$, $(K,H)(Al,Fe)\ SiO_4$, $NaAlSi_2O_6$, $NaFeSi_2O_6$.

Let us first consider those free from alkalis. Upon the general assumption that the alkalis control an equal amount of alumina, the introduction of ferromagnesian-ferroaluminous molecules would demand an increase in the alumina over that necessary to satisfy the alkalis. This must take place at the expense of the ferromagnesian and calcium molecules in cases I and II, or at the expense of anorthite molecules, in case III.

Let us consider cases I and II. The molecule $(Mg,Fe)(Al,Fe)_2SiO_6$ is a subsilicate. The range of silica percentages for all manner of variations in its composition is from 29.52 for $MgAl_2SiO_6$ to 20.54 for $FeFe_2SiO_6$. The molecule usually is more nearly the average of these extremes. The silica range is indicated in Diagram 1 by the bracket, which shows that this molecule requires less silica than the orthosilicate of iron, considerably less than olivine, and very much less than diopside or enstatite. Its development, then, would extend the quartz limit and reduce the nephelite-leucite limit very considerably in proportion to its own amount. It may be stated that in general its amount is quite subordinate to that of the ferromagnesian ortho- and metasilicates. Its effect on magmas of case III, where anorthite occurs, would be of the same kind as the introduction of non-aluminous ferromagnesian silicates, but the degree of the change would be greater in proportion to the number of molecules introduced.

Turning to the alkali-ferroaluminous molecules, it is to be observed that one, $(K,H)(Al,Fe)SiO_4$, is well known to be capable of appearing in igneous rocks of almost any chemical composition in which its elements occur. Two others $(K,H)AlSiO_4$, and $NaFeSi_2O_6$ appear to occur in rocks with special chemical composition, while the fourth, $NaAlSi_2O_6$, is less well known but may be supposed to be of wide occurrence in small amounts. The first belongs to biotite. If the ratio between potassium and hydrogen varies from 1 : 1 to 1 : 2, and the aluminium and iron be supposed to reach their possible extremes, from normal biotite to lepidomelane, the range in silica percentage for this orthosilicate molecule would be from 29.07 to 19.10, which is indicated by the bracket in Diagram 1. The relative proportions of potash and alumina vary from 1 : 1 to 1 : 2 in most instances. Sodium does not enter into the molecule to any considerable extent, the development of biotite then affects the potash-feldspathic molecules. In orthoclase rocks within the quartz limit its development would reduce the amount of orthoclase molecules, and would change a polysilicate into an

orthosilicate and liberate silica, increasing the amount of quartz or raising ferromagnesian orthosilicates to metasilicates. But the development of biotite would draw upon the ferromagnesian orthosilicate $(Mg,Fe)SiO_3$, reducing the amount that might be converted into metasilicate. The quartz limit would then be shifted toward lower silica percentages. In orthoclase-leucite rocks, or leucite rocks without orthoclase, the development of this potash-ferroaluminous molecule would reduce the amount of these minerals and liberate silica, which would raise the metasilicate leucite to orthoclase. The effect would thus be to cause the leucite limit to recede toward lower silica percentage.

It has already been noted that the development of biotite involves, besides the potash-bearing molecule under discussion, an orthosilicate of iron and magnesium, which is the same as an olivine molecule. The development of this molecule in rocks that might otherwise carry ferromagnesian metasilicate molecules would still further liberate silica, to appear as more quartz or raise more leucite to orthoclase.

In case alumina is in excess of potash in this mica molecule the excess of alumina must be drawn from an excess of alumina over the alkalis originally in the rock, or it must be drawn from a sodium-aluminium molecule, since no potash molecule, in which potash exceeds alumina, occurs to any extent in the pyrogenetic minerals according to present theories. In the second instance the effect would be to reduce the albite or nephelite molecules and drive the soda into combination with ferric iron, affecting the distribution of the silica.

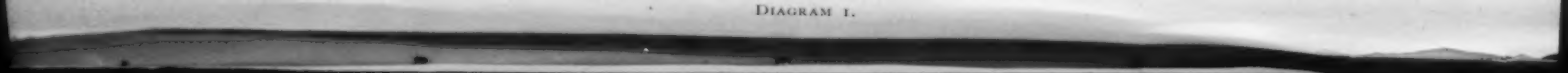
The development of the metasilicate molecule, $NaAlSi_2O_6$, which enters amphibole, would reduce the albite molecules with the liberation of silica and the possible production of quartz, or the raising of nephelite to albite. It would reduce the nephelite molecules if it did not affect those of albite, and would require additional silica, which would have to be drawn from a polysilicate (orthoclase) or from a metasilicate. It does not appear to enter largely into the composition of rock-making amphiboles,

except possibly into those crystallized from magmas rich in soda and alumina.

The molecule (H,K) Al Si O_4, with little or no iron and with hydrogen and potassium, usually in the proportion of 2:1, occurs as muscovite. It is nearly identical with that occurring in biotite, except for lower iron. Muscovite occurs as a pyrogenetic mineral only in the most highly siliceous and quartzose rocks, where it is sometimes accompanied simply by quartz and alkali feldspar. The fact that this molecule often carries three times as much alumina as potash, and the absence of other potash molecules in which potash occurs in greater amount than alumina, indicates that the muscovite molecule develops in magmas in which alumina is in excess of the alkalis. Its presence bears no direct relation to the percentage of silica in the rock. Its absence from many rocks in which alumina is in excess of alkalis is probably due to its combination with iron and magnesia, resulting in the formation of biotite. Magmas sometimes occur with so large an excess of alumina that it crystallizes as corundum, Al_2O_3, in association with alkali-feldspars. The alumina in these cases did not enter muscovite molecules with the potash.

The development of the sodium-iron-metasilicate, Na Fe Si_2 O_6, which occurs in pyroxene, as the acmite molecule, and also in riebeckite, is pronounced in magmas rich in sodium and ferric iron; Fe_2O_3 appearing to take the place of Al_2O_3. Considered in connection with the composition of rocks of case I and III, Diagrams 1 and 2, its presence reduces the amount of albite, and increases the silica available for quartz or for raising nephelite molecules to albite according to the position of the rock in the scheme. Its presence would therefore shift the quartz limit toward lower silica percentages. It does not appear to play any considerable rôle in rocks low in soda or in ferric oxide.

It is not the plan of the present paper to discuss the effect on the mineral composition of rocks of the development of the less abundant or subordinate minerals. In some cases their production is clearly due to the presence of special elements,



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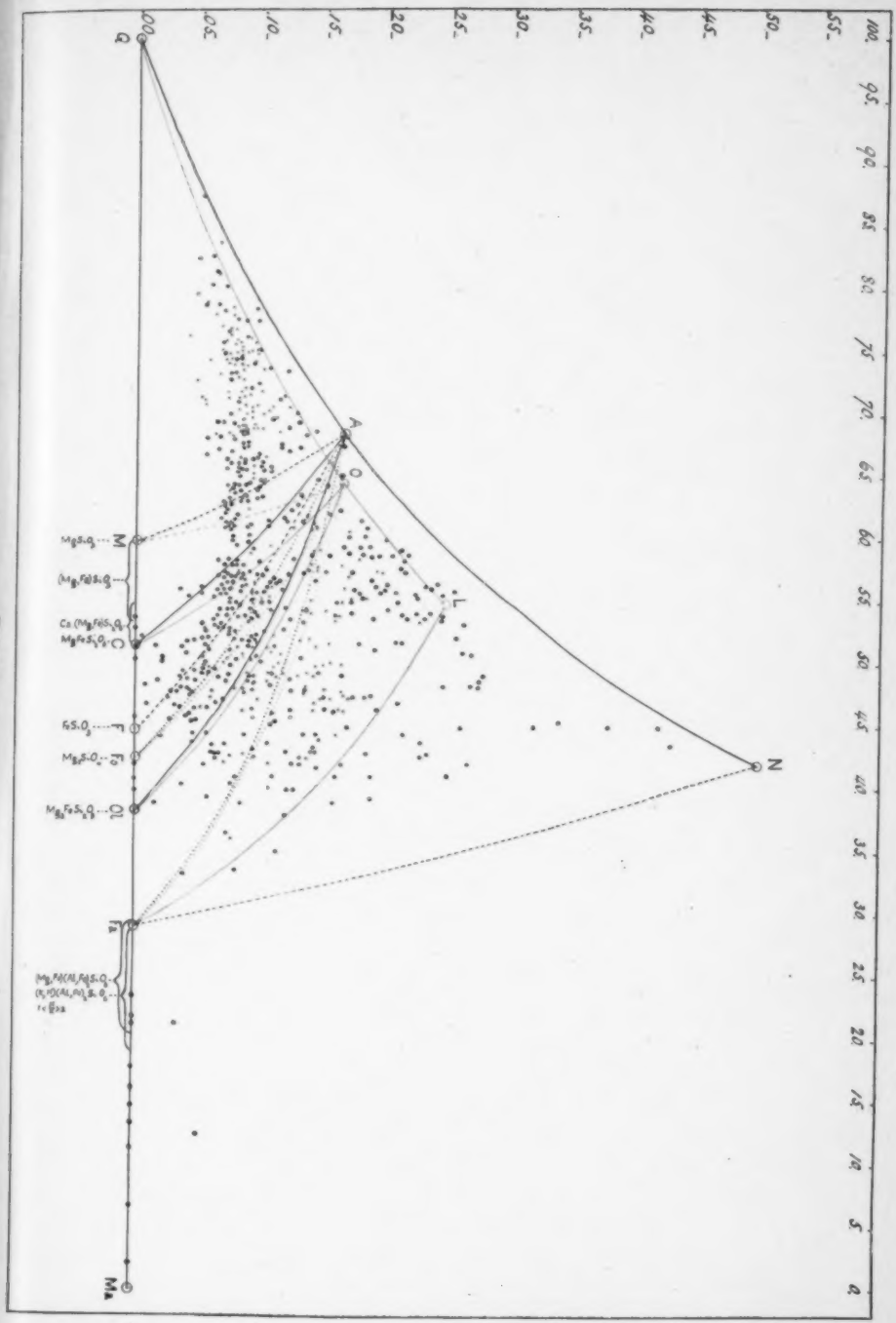
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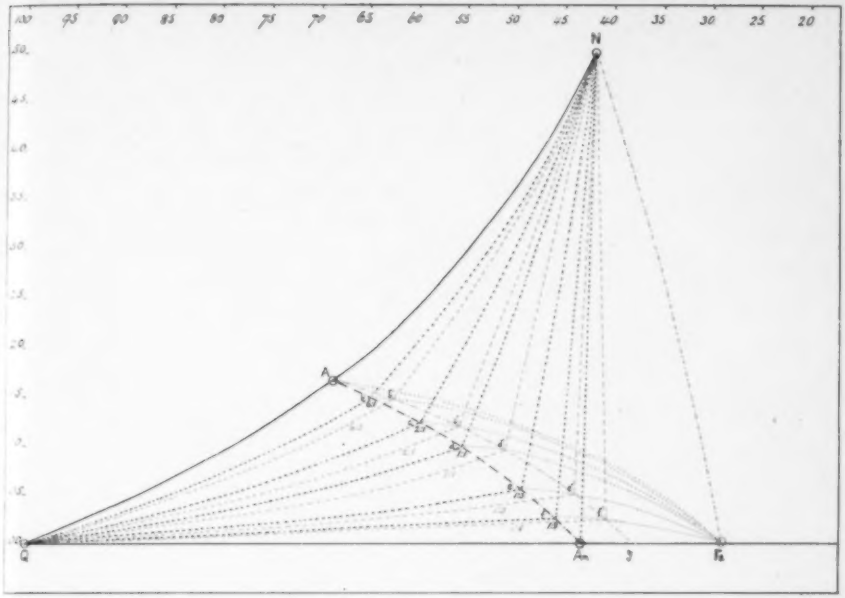


DIAGRAM 2

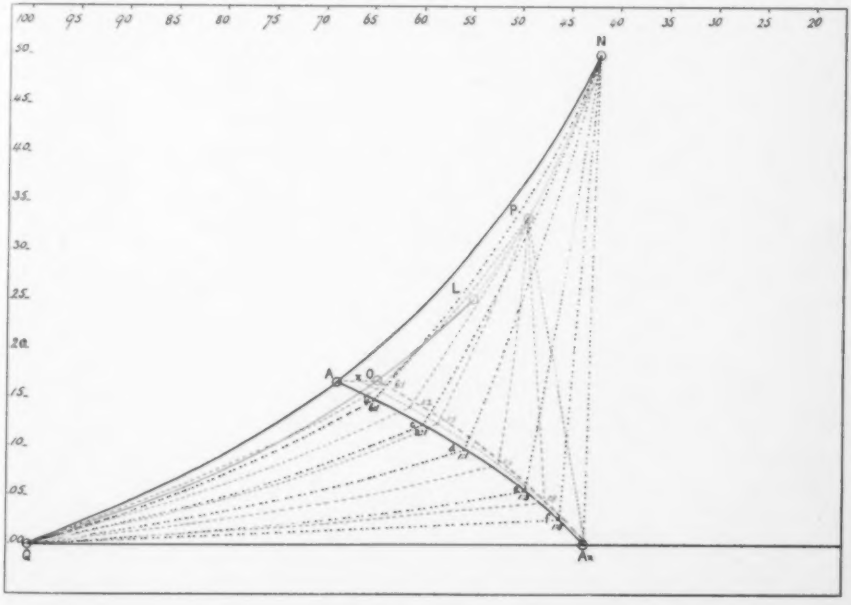


DIAGRAM 3

such as phosphorus, titanium, zirconium, sulphur, chlorine, fluorine, boron, etc., and their influence in modifying the proportions of the preponderant minerals is self-evident.

The discussion has been far from complete, but it is hoped that it may lead to a better understanding of the relations between the chemical and mineral composition of igneous rocks, especially the factors controlling the range of quartz on the one hand and of leucite and nephelite on the other. It certainly makes more evident the interdependence of the various minerals on one another and on the chemical composition of the magma. And it may possibly suggest lines of investigation that may contribute more substantially to our knowledge and conception of these intricate relationships. JOSEPH P. IDDINGS.

THE WEATHERED ZONE (YARMOUTH) BETWEEN THE ILLINOIAN AND KANSAN TILL SHEETS.[1]

PRELIMINARY STATEMENT.

THE full extent of the overlap of the Illinoian upon the Kansan has not been determined. It is certain that a sheet of Kansan drift underlies the Illinoian throughout its extent in southeastern Iowa, and in all probability it continues some distance eastward into western Illinois, in the section between Rock Island and Quincy.

There may be a sheet of Kansan age formed by the Illinois glacial lobe. The available data, however, do not place this beyond question. Occasional wells in central Illinois are reported to have passed through a black soil at some distance below the Illinoian till. But, so far as the writer is aware, no exposures of such a soil have ever been discovered. Professor Salisbury has collected data in southeastern Illinois and southwestern Indiana which support the view that there may be two distinct drift sheets in that region. It is his opinion that the upper or Illinoian sheet extends farther south than the lower sheet.[2] Whether the lower sheet is of Kansan age is still a matter for conjecture. It also is still an open question whether the drift of the east border of the driftless area in northwestern Illinois and southwestern Wisconsin is of Illinoian age or of earlier date. In view of these uncertainties this discussion of the Yarmouth weathered zone is restricted to the region where the Illinoian sheet of the Illinois lobe overlaps the Kansan sheet of an ice lobe lying farther west.

Numerous exposures of a soil and weathered zone have been observed at the junction of the Illinoian and the Kansan till sheets in the region of overlap between Davenport, Iowa, and

[1] Read before the Iowa Academy of Sciences, December 1897.

[2] Communicated to the writer.

Quincy, Illinois. The presence of this soil horizon was first brought to the writer's notice by a well section at Yarmouth in Des Moines county, Iowa. For this reason, and because the name of this village is less likely to be confusing than names which are more common, it seems appropriate to apply the name Yarmouth to this weathered zone. There is also at Yarmouth not only a soil horizon, but apparently a pronounced erosion between the Illinoian and Kansan sheets.

THE YARMOUTH SECTIONS.

About ten years ago, Mr. William Stelter, of Yarmouth, Iowa, sunk a well near that village which passed through a bed of peat at the base of the Illinoian till sheet. The peat contained small bones which have been identified by Dr. F. W. True, of the United States National Museum, as (1) a portion of the pelvis and upper part of the femur of the wood rabbit (*Lepus sylvaticus*), and (2) the scapula of the common skunk (*Mephiticus mephitica*). The following section is based upon a statement made by Mr. Stelter soon after the well was dug and upon specimens of the several classes of material penetrated, which were also furnished me for examination:

	Feet.
Soil and loess loam,	4
Yellow till (Illinoian),	20
Gray till (Illinoian),	10
Peat bed with twigs and bones,	15
Gray or ashy clay containing fragments of wood,	12
Fine sand,	16
Yellow sandy clay with few pebbles (Kansan),	33
Total depth,	110

One mile south of Yarmouth, on the farm of Mr. F. Smith, a well was in process of excavation during a visit made by the writer to that region some years later, and the following section was determined by examination of the material in the dump, and with explanations by the well-borer. The well is located on a high point on the ridge marking the border of the Illinoian

drift, perhaps 25 feet higher than the village of Yarmouth, which also stands on the ridge. It will be observed that the black muck penetrated in this well is at a level fully 40 feet lower than in the well at Mr. Stelters. This difference in level is interpreted to be due to one well having struck into a valley cut into the Kansan drift, while the other well entered the Kansan drift near the level of the bordering uplands.

SECTION OF WELL AT F. SMITH'S, NEAR YARMOUTH.

	Feet.
Yellow till (Illinoian),	36
Sand with thin beds of blue clay and also of cemented gravel,	73
Black muck containing wood,	6
Sand and gravel, probably alluvial,	8
Gray silt nearly pebbleless, apparently alluvial,	15
Blue till (Kansan),	42
Total depth,	180

If my interpretation of the records at Yarmouth is correct, there is here not only a notable accumulation of peat and muck between the Kansan and Illinoian, but also an erosion of the Kansan till sheet to a depth of 40 feet prior to the deposition of the Illinoian. Since these sections are based entirely upon well records, they afford a less clear idea of the relation of the beds than might be afforded by valley excavation.

Exposures in neighboring districts. — One of the most satisfactory exposures yet found is that afforded by a ravine about one mile northeast of West Point, in Lee county. This was first seen by the writer in 1894. The following section may be obtained by descending the gully at the roadside:

	Feet.
Surface silt (loess),	6
Black soil with ashy gray subsoil,	5
Brown till containing many bowlders, among which were two red jaspery conglomerates (Illinoian),	15
Black mucky soil with gray subsoil (Yarmouth),	6
Brown clay with few pebbles (Kansan),	15
Total,	47

This exposure was visited by Professor T. C. Chamberlin and Dr. H. F. Bain in August 1896 and by each the black material beneath the till was considered a typical soil, and the gray material below a typical subsoil. The slightly pebbly brown clay beneath this subsoil shows no response with acid. Other exposures, however, have been found in which a response with acid may be obtained within six feet below the base of the lower or Yarmouth soil.

Between West Point and Denmark, a distance of seven miles, records of thirteen wells have been obtained in which a soil was found between the Illinoian and Kansan till sheets. The thickness of the soil ranges from 2 to 5 feet and its depth below the surface ranges from 16 to 45 feet; the usual distance to the soil is about 30 feet. This represents, therefore, the combined thickness of the Iowan loess and Illinoian till sheet. The loess, however, has a depth of but 5 to 10 feet. Of several wells made at Denmark in 1894 to 1897 the writer has witnessed the excavation, and finds that the leaching beneath the lower soil extends about 6 feet into the Kansan till sheet. One of the most satisfactory sections near Denmark is the following, made on the farm of Mrs. Van Tuyl:

	Feet.
Surface silt or loess of yellow color slightly calcareous and containing a few small pebbles near base,	7
Brownish yellow till, slightly calcareous and with few pebbles (Illinoian),	10
Brownish yellow till very pebbly and calcareous (Illinoian),	8
Blue clay with few pebbles (Illinoian),	10
Black mucky soil with wood (Yarmouth),	2
Brownish yellow till (Kansan),	12
Hard blue till (Kansan),	6
Limestone,	4
Total	59

In this connection it may be remarked that several of the wells in the vicinity of Denmark pass through 25 or 30 feet of oxidized Kansan till and enter rock without striking a blue till, but exposures in ravines both north and south of the villages

show a dark blue-black till thickly set with fragments of wood. This occurs at a level lower than the rock surface at Denmark and has a striking similarity to exposures in other parts of the state which are suspected to be pre-Kansan in age.

Exposures at Davenport, Iowa.—The Illinoian till sheet as above noted is known to overlap the Kansan as far north as Davenport, Iowa. There are excellent exposures of both sheets within the limits of that city and also at points a few miles west near Blue Grass. An exposure in Davenport on Eighth st. between Myrtle and Vine was discovered by Professor J. A. Udden and has been visited by Professor Calvin, Mr. Bain, and the writer, each of whom recognizes the presence of both sheets of drift and also the Yarmouth weathered zone. The surface of the Kansan till sheet has the appearance of slight erosion, for it shows a rise of about 15 feet in a distance of 20 or 30 rods. The Illinoian till sheet rests unconformably upon the eroded Kansan, reaching a lower level at the south end of the exposure than at the north. In making the descent along Eighth st. the following series of beds was found:

	Feet.
Loess,	30
Weathered zone of reddish brown till (Sangamon),	3
Unleached brown till (Illinoian),	15
Weathered zone of gummy gray clay (Yarmouth),	3
Brown till changing to gray color, 12 to 15 feet (Kansan),	30

Exposures in Adams county, Illinois.—The most southerly exposures of the Yarmouth weathered zone yet observed are in Adams county, Illinois. In a ravine near Woodville in the northern part of the county two sheets of brown till appear which are separated by a gray gummy clay. This clay is thoroughly leached, while the till immediately above it is unleached. The latter has a thickness of only 10 or 12 feet. Another exposure was found at a well in process of excavation on a farm eight miles east of Quincy. This section is similar to that in the ravine except that the Illinoian till sheet has a thickness of 20 feet. Another exposure was found north of Payson near the

base of a ridge of Illinoian drift. The gray clay here rests upon a gravelly bed instead of a sheet of till, but appears to be of similar origin and age to the other beds referred to the Yarmouth stage.

Within a few miles south from this exposure the border of the Kansan drift emerges from the edge of the Illinoian and passes southward into Missouri. The driftless peninsula found by Professor Salisbury here sets in and occupies a narrow strip west of the Illinois from Pike county to the mouth of that stream,[1] beyond which the margins of the Illinoian and Kansan sheets take widely divergent courses. Fortunately there was sufficient overlap north from this driftless peninsula to make clear the interpretation that the Illinoian is a markedly younger sheet than the Kansan. This difference in age was suspected to occur from a comparison of maturity of valleys in the two districts, but the testimony of the weathered zone preserved below the Illinoian was necessary to confirm it.

FRANK LEVERETT

DENMARK, IOWA.

[1] See Proc. A. A. A. S., Washington meeting, 1891, pp. 251–253.

THE PEORIAN SOIL AND WEATHERED ZONE (TORONTO FORMATION ?)[1]

THE interval between the Iowan and Wisconsin stage of glaciation has been provisionally named Toronto by Professor Chamberlin, because of excellent exposures of interglacial fossiliferous beds along the Don Valley in Toronto, Ontario, which may prove to have this age.[2] Professor Chamberlin remarks in connection with the introduction of this name that the grounds for this correlation are not very strong, and further investigation may show them to be erroneous, but that it is not likely that the beds upon the Don can be referred to any earlier period. He further remarks, that, "Whether the beds on the Don belong to the horizon suggested or not, it is certain that vegetal beds were formed in the interval of the retreat between the formation of the Iowan till and the formation of the Wisconsin till, and some of these less well developed and less known deposits must be looked to as a type of this interglacial horizon if the Toronto beds prove unavailable."

In view of the uncertainty attached to this correlation, it seems advisable to employ for the present a substitutional name which is known to be applicable to the interval between the Iowan and the early Wisconsin. In case the correlation suggested by Professor Chamberlin is demonstrated to be correct the name Toronto has precedence.

Extensive deposits of muck and peat occur at the base of the Wisconsin drift in northern Illinois, notably in McHenry, Kane, De Kalb, La Salle, and Bureau counties, which are in all probability immediately underlain, in some cases at least, by

[1] This paper forms part of an unpublished report by the writer on the Illinois glacial lobe. It is published in connection with the two papers read before the Iowa Academy because of the close relation of the subject-matter.

[2] Classification of American Glacial Deposits, by T. C. CHAMBERLIN, JOUR. GEOL., Vol. III, 1895, pp. 270–277.

Iowan drift. In central and western Illinois the soil is in places underlain by a fossiliferous silt, referred with some confidence to the Iowan loess. In eastern Illinois the Iowan till may be present. This soil horizon, together with lower soil horizons, was discussed by the writer in a paper presented at the Cleveland meeting of the American Association for the Advancement of Science.[1] At that time the separation of the Iowan sheet from the Illinoian had not been made and all the soils were referred to a single horizon. The later developments have led the writer to separate the soils found at, or slightly below, the Wisconsin drift into two classes—one class being thrown into the Sangamon stage, while the other is thrown into the stage under discussion. It is not possible in all cases to decide to which class a buried soil should be referred, for in some cases its existence is known only through well records. The separations thus made are set forth in detail in a report by the writer yet unpublished.

In selecting a name for the horizon, the ideal locality would be one in which the earliest sheet of Wisconsin till overlies the Iowan till. In the vicinity of Marengo, in McHenry county, a black muck has been found at the base of the Wisconsin drift, and it apparently rests on Iowan till. This might be taken as a type locality were it not that the Wisconsin drift at that point may not include the Shelbyville or earliest Wisconsin sheet of till. The same objection may be urged against buried soils found in Kane, De Kalb, La Salle, and Bureau counties, for in all these counties the outer Wisconsin ridge appears to be the Bloomington moraine, and the limits of the Shelbyville may be to the east of this ridge. It has seemed advisable, therefore, in the selection of a type locality to pass to central Illinois, where the Shelbyville sheet extends beyond the later sheets of Wisconsin drift. This, unfortunately, carries us beyond the Iowan till, but the loess, whose deposition seems to mark the close of the Iowan glaciation is there well developed. The interval between the loess and Shelbyville till sheet probably marks as

[1] For abstract of paper see Proc. A. A. A. S., 57th meeting, 1888, pp. 183–184.

well the time between the culmination of the Iowan and Wisconsin glaciations as if taken where the Shelbyville sheet overlies Iowan till.

The loess has been traced back in valley exposures several miles beneath the Shelbyville till sheet in northern Tazewell county, Illinois, and beneath the combined Shelbyville and Bloomington sheets in Woodford and Bureau counties. Farther south it has been recognized in well sections in southern Tazewell, northeastern Logan, western De Witt, southern Macon, and western Sullivan counties, Illinois. The phase of loess known as white clay has been traced several miles up the Kaskaskia and Embarras valleys in Shelby and Coles counties beneath the Shelbyville till sheet.

Of the several exposures those east of Peoria in northern Tazewell county are the best displayed. Decisive evidence is also found at these exposures of an interval of some length between the deposition of the loess and the deposition of the overlying Shelbyville till sheet. In view of these conditions in the vicinity of the city of Peoria it has seemed appropriate to apply the name Peorian to the interval between the Iowan loess and the Shelbyville till sheet, a till sheet which appears to be the earliest of the Wisconsin series.

In exposures along the T. P. & W. R. R., east of Peoria, and also on the east bluff of the Illinois opposite that city, the Shelbyville sheet is underlain by a bed of fossiliferous loess, similar to that found on the surface of the Illinoian outside the limits of the Shelbyville drift sheet, both in texture and in age. The loess is 8 to 12 feet in thickness, or about the same as on the uplands outside the Shelbyville sheet. It occurs at a corresponding elevation of about 200 feet above the Illinois River. Beneath it there is exposed fully 100 feet of the older drift sheet.

The upper part of the loess to a depth of two or three feet presents a reddish brown color, and is thoroughly leached. The leaching extends usually to a depth of about six feet. But beneath that depth the loess is often calcareous. The Shelby-

ville till was found to be very calcareous immediately above the loess. The evidence of a weathered zone at the top of the loess is as clearly shown as at the top of the underlying Illinoian till and several exposures occur in which the two weathered zones may seem in vertical sections. It is probable, however, that such a zone would be developed more rapidly in the loess than in the till, because of the greater porosity of the former.

Evidence of an interval between the Iowan and early Wisconsin glaciations is found in the great dissimilarity in the outline of the two ice sheets. The outline is more out of harmony, both with the early Wisconsin and the Illinois, than the outline of those sheets with each other. The great extension toward the south border of the driftless area, both in the Iowa and Illinois lobes of Iowan ice is singularly out of harmony with both succeeding and preceding glaciations. The shifting of lobes involved in the change from the Iowan to the early Wisconsin can scarcely be assumed to have occurred in a brief interval. The moraine-forming habit of the Wisconsin and absence of distinct morainic belts in the Iowan also implies a change in glacial conditions that can scarcely be assumed to have taken place suddenly.

Evidence of an interval between the deposition of the Iowan loess and associated silts, and that of the Shelbyville till, is found in a change in the attitude of the land which resulted in a marked deepening of the valleys. There appears to have been a greater depth of excavation during the Peorian interglacial stage than during the Sangamon. The breadth of excavation, however, was reduced to but a fraction of that in the Sangamon stage. The amount of change in altitude can as yet scarcely be even conjectured, much less demonstrated, but its effects on the drainage are such as to support the view that it denotes a time interval of considerable length; a view which is also supported by the work accomplished in deepening the valleys. Comparing the work with substages of the Wisconsin it appears that the interval may not greatly exceed that between the Shelby-

ville and Bloomington ice advances. The Shelbyville sheet had apparently become channeled by streams prior to the Bloomington substage of glaciation to nearly as marked a degree as the channeling below the level of the loess effected in the Peorian stage of deglaciation. There is also a marked increase in the stream gradient, the Bloomington drift sheet being accompanied by a much more vigorous gravel outwash than that which accompanies the Shelbyville sheet. In the writer's opinion it is questionable if the interval between the Iowan and early Wisconsin invasions covers more than a comparatively small part of the time occupied by the intervals between the Iowan and Illinoian, and between the Illinoian and Kansan. The union of the several lines of evidence just cited would seem to support the view that it is longer than interglacial substages of the Wisconsin. The view of a brief interval between the Iowan and Wisconsin meets a strong objection, however, in the supposed attendant deposits at Toronto.

Turning to the Toronto formation it is found that a fossiliferous silt occupying a horizon between bowldery glacial clays has a fauna and flora which denote a climate fully as mild as at present characterizes that region.[1] In discussing this formation Dr. A. P. Coleman remarks that unless the Labrador gathering ground is shown to have stood much higher than at present it can scarcely be supposed that a widespread sheet of ice was maintained there, while oaks and maples and pawpaws flourished on the land and Mississippi unios in the waters within 400 to 500 miles to the southwest. In the absence of any evidence of such an uplift he concludes that the ice fields were completely melted during this interglacial epoch. Professor D. P. Penhallow remarks that the arborescent forms of vegetation in these interglacial beds are of species such as may now be found in the same region.

[1] See descriptions by DR. A. P. COLEMAN and PROFESSOR D. P. PENHALLOW in American Geologist, Vol. XIII, Feb. 1894, pp. 85–95. See also additional interpretation by DR. COLEMAN, in JOUR. GEOL., Vol. III, pp. 274, 622–645.

For description of fossiliferous beds at Scarborough Heights and other localities near Toronto, by DR. G. J. HINDE, see Journal of the Canadian Institute, April 1877.

The extent of deglaciation suggested by these beds, so far as space is concerned, can scarcely be supposed to have been exceeded either by the Sangamon or the Yarmouth stage of deglaciation. The Toronto beds constitute probably the most decisive evidence yet brought forward in support of an extensive deglaciation within the glacial period. The time involved may reasonably be supposed to involve a portion of the glacial period by no means small. Its rank should be as high as that of any of the interglacial stages, even if less prolonged than some of the earlier stages of deglaciation. Should it be proved to represent the interval between the Iowan and Wisconsin deposits, as now seems probable, the evidences above cited, from the peripheral portion, may aid in determining its length, namely, the leaching and erosion of the Peorian stage. As yet the fauna and flora buried beneath the peripheral portion of the Wisconsin drift have received little or no attention. Possibly by the aid of this line of study the question of correlation may be settled.

FRANK LEVERETT.

A GEOLOGICAL SECTION ACROSS SOUTHERN INDIANA, FROM HANOVER TO VINCENNES.

INTRODUCTION.

DURING the field season of 1896 the Indiana University Geological Survey undertook to map, geologically and topographically, a section across southern Indiana, reaching from the Ohio River at Hanover on the east, to the Wabash River at Vincennes on the west. The strip of country mapped is 6 miles wide, 120 miles long, and is embraced in the row of townships numbered 3 north.

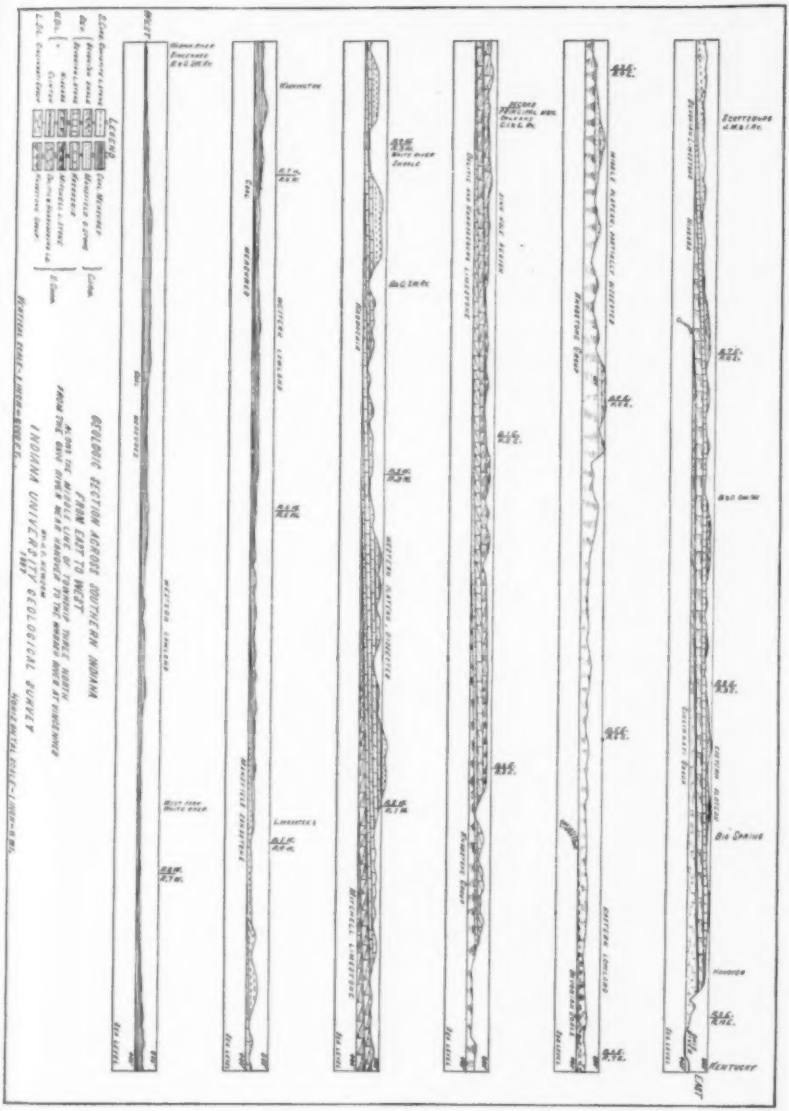
METHOD OF RUNNING THE SECTION.

The topographic work was done by means of aneroid barometers, with a line of levels through the territory by which the aneroid readings were checked. This line was run as far as Willow Valley station in Martin county, and as near the middle of the strip of country to be mapped as the conditions would permit; the elevations were obtained by means of the vertical arc, and are as accurate as the necessities of ordinary topography and geological cross sections demand. The line of levels was checked on the J. M. & I. and the B. & O. S.-W. R. R., where these roads were crossed. The dips of strata as shown by these levels may be depended upon within the suggested limits.

The section chosen was selected because the geological horizons and the topography crossed by it are typical of almost the entire southern part of the state. The geological horizons cannot be taken up here in detail, but it is desired to point out some of the relations existing between the topography and the geology.

THE HORIZONS CROSSED AND THE RESULTING TOPOGRAPHY.

The eastern plateau.— Beginning in the east near Hanover, at the west side of township 3 north 10 east, the lowest rocks


GEOLOGIC SECTION ACROSS SOUTHERN INDIANA
FROM EAST TO WEST
ALONG THE MIDDLE LINE OF TOWNSHIP THREE NORTH
FROM THE OHIO RIVER NEAR VANDUSEN TO THE WABASH RIVER AT VINCENNES
INDIANA UNIVERSITY GEOLOGICAL SURVEY
LEGEND
Coal Measures
Subcarboniferous
Devonian
Silurian
Ohio River
Wabash River
Kentucky
Indiana

exposed in Indiana are the limestones and calcareous shales of the Cincinnati group. Near Hanover these beds have an exposed thickness of about 250 feet, reaching from near the tops of the bluffs along the Ohio River down to and below the level of that stream, which at this place is about 400 feet above mean tide. Overlying this series of soft strata are hard limestones belonging to the Clinton, Niagara, and Devonian (Corniferous). The combined thickness of these beds is about 180 feet.

The limestones resist the action of the weather, and owing to these hard, resisting strata above, and the soft, easily eroded strata below, the conditions are favorable to the formation of bluffs and waterfalls. So it happens that each short stream that flows eastward into the Ohio has the upper end of its gorge marked by a precipice or waterfall, varying in height from 40 to 90 feet.

When the top of the limestone is reached the country immediately becomes approximately level. The Devonian limestone is overlain by the Devonian black shale, and as this shale has no hard beds immediately overlying it, it does not produce a rugged topography. The dip of the Devonian limestone from Big Spring, township 3 north 9 east, section 16 to section 20, 3 north 8 east is 231 feet, or a little over 33 feet to the mile. This dip is not constant, but varies from 20 to 46 feet per mile, and is in every respect sufficient to cause the westward flow of the streams.

In the eastern edge of Scott county the westward dip of the Devonian limestone and the overlying Devonian black shale is probably at its minimum; the hills of this locality, and the exposures of limestone in the valleys, are probably due to this structural feature. While the hills are not high—ranging from 50 to 100 feet above the valleys—they nevertheless form the most marked topographic feature between the Ohio River and the Knobs.

The Devonian limestone finally passes beneath the drainage near the west line of township 8 east, the country immediately

to the west becomes more gently rolling, and the low hills are made up of black shale covered over in most cases by glacial material.

The Devonian black shale outcrops over a strip of country some twelve miles wide. Except at its eastern edge where it has been eroded to a feather edge, and where the underlying limestone controls the topography, it forms very low hills, and often almost flat plains. The black shale passes beneath the drainage near Scottsburg. In a deep well drilled at Scottsburg its thickness was found to be 120 feet.

The eastern lowland.—Overlying the Devonian black shale is the Knobstone group of clay shales, sandy shales, and sandstones. The lower limit of this group is marked by the Rockford Goniatite limestone, which, owing to its thinness has but little effect on the topography. The lowest beds of the Knobstone group are made up of clay shales. These clay shales, with the underlying Devonian black shale, are directly responsible for the low country and very gentle topography to be found throughout southern Indiana, between the high escarpment known as the Knobs, and the deep gorge of the Ohio River. The western part of this region may be properly styled the eastern lowland.

One noticeable feature of the topography from the top of the escarpment near Hanover, where the elevation is 800 feet above tide, to Scottsburg (570 feet above tide), is the gradual westward slope of the country, corresponding almost exactly to the average dip of the strata. The tops of the low hills of this region are all found in approximately the same slightly westward dipping plain.

The "Knobs" and the middle plateau.—The Knobs form by far the most important topographic feature in the eastern part of the extreme southern portion of Indiana. They are made up of Carboniferous strata belonging to the "Knobstone group" with its capping Carboniferous limestones. The Knobs do not form a range of hills, properly speaking, but are rather a high escarpment, generally facing eastward, with a plateau sloping

very gently to the west, and with outliers to the east. The geological conditions, so far as they bear upon topography, are very similar to those along the Ohio River, to the east, *i. e.*, a thick series of soft and unresisting strata is capped by sandstone and more resisting limestones, thus making possible bold hills and steep slopes.

The parting between the Knobstone and the overlying limestone is not a sharp one, but is made up of interstratified limy and sandy layers, indicating a gradual change in the conditions of sedimentation. The easternmost point in the line of parting between the Knobstone group and the overlying limestone is at the southeast corner of section 18, 3 north 5 east. Passing on westward the top of the Knobstone is found lower and lower in the hills, until it finally passes beneath the drainage in the northeast quarter of section 19, 3 north 3 east, at an elevation of 537 feet, or 342 feet lower than its outcrop, just eleven and one-half miles east. This shows a general westward dip averaging about twenty-six feet per mile.

The sink hole region.—Overlying the Knobstone group, and still dipping to the west are the Harrodsburg and Mitchell limestones (of Hopkins and Siebenthal), and the Kaskaskia group, all belonging to the Lower Carboniferous. In the region of its easternmost exposure the limestone is very thin, being eroded to a feather edge. Passing westward from its easternmost exposure, it is found lower and lower in the hills, because of its westward dip, and the country becomes accordingly less rugged and takes on the gently rolling and pitted sink hole character common in limestone regions.

In this region and on westward across the outcropping Mitchell limestones, and until the Kaskaskia beds are reached, the country has a very gentle westward slope. This is less, however, than is to be found east of the "Knobs," and it is also less than the dip of the rocks; this is due to the fact that the limestones do not weather so easily as do the shales.

There is a noticeable increase in the size of the sink holes in going across the limestone region from east to west. The sink

holes at the eastern edge are rarely more than 20 feet deep and 200 yards across, while in the western part they are sometimes miles in length and from 50 to 200 feet deep, forming valleys, similar in every respect to ordinary valleys of erosion, except that they have no surface outlets for their drainage. The increase in the size of the sink holes is, of course, due to the greater thickness of the underlying limestone.

The western edge of the Mitchell limestone is found just west of the second principal meridian, where, overlying it, is the lower Kaskaskia limestone, a hard, close-grained, resisting bed, which is in turn overlain by a series of limestones and sandstones. The effect of these beds upon the topography is quite noticeable. The hills rise higher and higher to the west, until on the western edge of Lawrence county, where they are capped by the highest beds of the Kaskaskia group, they are from 100 to 250 feet above the valleys. Many of these valleys are only large sink holes, and have no surface outlets.

The Mansfield sandstone, or western plateau.— Overlying the Kaskaskia beds is the Millstone grit (Mansfield sandstone of Hopkins) or the sandstone that forms the lowest member of the Upper Carboniferous. This sandstone controls the topography in the region in which it forms the surface rock, and is, in the main, responsible for the high hills of Martin county. It has a gentle westward dip and owing to this fact the highest hills of the region are found near its eastern limit. The hills decrease in height with the dip of the rocks to the west. The resulting topography is essentially that of a thoroughly dissected plateau.

The western lowland.—The Mansfield sandstone is finally lost to view at the western edge of Martin county, a short distance east of Loogootee. West of this point the country is level, or very gently rolling. There is here an abrupt transition from the rugged hills capped with sandstone, in Martin county to the much lower, level country underlain by coal-bearing shales and sandstones at the east side of Washington county.

Overlying the Mansfield sandstone, and extending from its upper limit to the west line of the state, the country is underlain

by the coal-bearing shales and sandstones of the Upper Carboniferous. These beds are easily attacked by eroding agencies, and have, therefore, already been worn down very near to their base level of erosion (if, indeed, they have ever been high above that level), leaving a comparatively level flat country. This region is covered with more or less glacial material.

The accompanying profile section shows clearly these different topographic features, and also the relations between the topography and the underlying strata.

CONCLUSION.

In conclusion, attention should be called to the following points:

a. In passing from east to west across southern Indiana, three prominent topographic features are crossed, and these features are the results of combinations of strata as follows: (1) the high eastward escarpment along the Ohio River caused by a thick series of easily eroded calcareous shales overlain by thick and resisting limestones; (2) the high eastward-facing escarpment with its outliers to the east, known as the "Knobs." This escarpment is the result of a thick series of soft clay and sandy shales, protected by sandstones and resisting limestones. Along the line under discussion this escarpment is twenty-eight miles west of the escarpment along the Ohio; (3) the high hills of Martin county, which are the result of a series of limestones and sandstones capped by more resisting sandstones and which do not rise as an escarpment from the east, but become gradually higher, owing to the resisting nature of their lowest beds. The distance from the Knobstone escarpment to the highest hills capped with the Mansfield sandstone is about thirty miles.

b. The structure of each of these topographic features where crossed by the section is essentially the same in different stages of development, *i. e.*, that of a dissected plateau, sloping gently to the west. In the eastern, or the Devonian limestone plateau, in the region of Ohio, dissection has scarcely begun, as none except the streams flowing directly into the Ohio have deep

gorges, and these are only from one-half to one and a half miles long; in the middle, or Knobstone plateau, dissection has progressed much further than in the eastern one; while the western or Mansfield sandstone plateau has been completely dissected by its streams.

It is possible that this peculiarity in the amount of erosion that has taken place in these different plateaus is the result of the character and former upward extension of the overlying formations in each case.

c. The top of the eastern plateau where crossed by the section is 800 feet above the sea, that of the middle is 820 feet, and that of the western 880 feet above tide, while but a short distance to the north or south the topographic sheets show the elevations of these plateaus to correspond even more closely.

These closely corresponding elevations point strongly to the conclusion that the present topography of southern Indiana has developed from an old base level; a former plain of deposition, or a combination of the two, might, however, have given rise to the present conditions.

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NOTES ON THE OHIO VALLEY IN SOUTHERN INDIANA.

INTRODUCTION.

In recent years much work has been done on the streams and abandoned stream channels leading through or from glacial regions. The upper Mississippi, the Illinois, the lower Missouri, many smaller streams in Minnesota, Wisconsin, Illinois, and Iowa, the Wabash, and the upper Ohio have been examined more or less carefully, but on the lower Ohio, and more particularly that part between the falls at Louisville and the mouth of the Wabash, little or nothing has been done.[1]

The present paper deals with a portion of this unexamined region in Spencer county, Indiana. Spencer county is in the southwestern part of Indiana. With reference to the Ohio, it is about 130 miles below the falls at Louisville and 95 miles above the mouth of the Wabash.[2] The region is particularly interesting, because it is near the middle of the base of the unglaciated triangle of Indiana.

The following paper will discuss (1) an old cut-off of the Ohio, (2) a series of river sands and gravels which seem to be Tertiary, (3) a probable extension of the Lafayette sea up the Ohio valley, (4) peculiarities of the loess on the bordering hills, including an apparent twofold character of the loess, and (5) a record of continental oscillation furnished by the deposits at this point.

The three physiographic regions.— Physiographically, Spencer county may be divided into two parts, a plain and a hill region. The plain may be subdivided into three parts. First, a broad,

[1] JOUR. GEOL., Vol. III, "Preglacial Valleys of the Mississippi," by FRANK G. LEVERETT, pp. 745 and 759.

[2] For general location see Figs. 1 and 2. Enterprise is in the western part of the region described.

level plain extends southwest along the western boundary of the county. It has the same general trend as Little Pigeon Creek, and will therefore be called Pigeon Plain, although this valley is not now occupied by Little Pigeon Creek.[1]

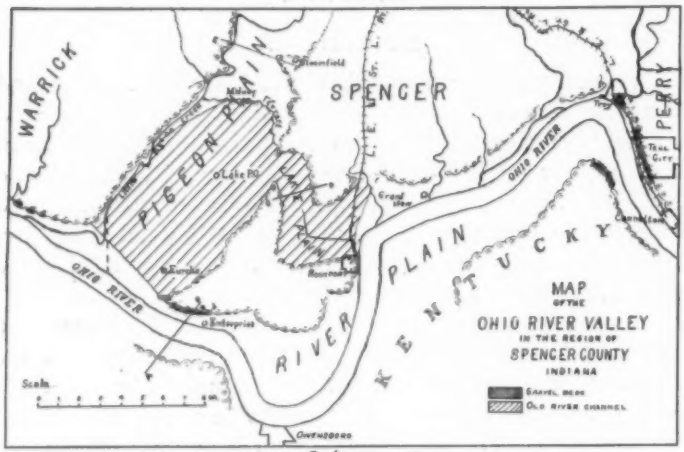


Fig. 1

Pigeon Plain is naturally divided into two portions by a terrace about fifteen feet high, which begins near the point where Lake Plain joins it, and extends in a general northwesterly direction past Midway to Little Pigeon Creek (Fig. 1). The plain north of this line is about fifteen feet higher than the portion south. The soil north is a reddish clay in part of the region and a very black peaty soil in the other; while the soil south is entirely different, being the same as that which makes the river bottoms and the River Plain, into which it merges at its south end. Other differences between the northern and southern parts of Pigeon Plain will be mentioned later.

Where Pigeon Plain enters the northern part of the area under consideration it is about two miles wide. It gradually

[1] The separation of Pigeon Plain and the valley of Little Pigeon Creek is not shown.

widens until at Midway it is about four miles and at Lake P. O. five, at which width it continues until it enters the second division of the plain region, the River Plain of the present Ohio.

The average width of the River Plain is between four and

MAP OF COAST LINE DURING THE LAFAYETTE ACCORDING TO McGEE, SHOWING ALSO SUPPOSED EXTENSION UP THE OHIO VALLEY

five miles. That portion which lies in Indiana is very irregular on account of the meandering course of the river. It includes all land locally termed the river bottoms. Three and a half miles below Enterprise, River Plain merges into Pigeon Plain.

The third portion of the plain enters, or rather leaves, the River Plain between Grandview and Rockport (Fig. 1), its southern portion including part of the town of Rockport. It is here three miles wide, but soon narrows down to two miles. It extends westward three miles, where it turns abruptly northward, and there narrows to about one mile. After going three miles in this direction it turns westward again, and enters Pigeon Plain two miles east of Lake P. O. The narrow part of this plain was occupied by a shallow pond of water when this country

was first settled. This pond was called "The Lake" by the early settlers. For this reason this division may be termed Lake Plain, although the lake is a result and not a cause of the plain.

These three plains so merge into one another that it is impossible to tell where one begins and the other ends. The average level of the plain above low water in the Ohio at Rockport is about thirty-five feet. The difference in levels of all three is very slight, not being over twenty feet, except where trenched by modern channels. The surface is so nearly level that large portions of this county either are or were swampy.

The hill region occupies all land not occupied by the plains above outlined. It will be seen from the location and interconnection of these plains that the south part of the hill land is completely cut off from the north or main upland, and stands as a roughly triangular tract, with channels or low plains on every side.

This region is characterized by a great number of hills rising on an average from forty to sixty feet above the plain. The highest part of the triangular hill land is in Rockport, near the junction of Lake and River plains, where the hills rise 110 feet above the plain. The next highest is at the junction of Pigeon and River plains, where the hills reach the height of ninety feet; the bordering hills being in general higher than those in the interior and the hills on the south and east higher than those on the west.

The northern portion of the hill land is higher and more irregular. The highest point measured is about four miles north of Rockport, where one of the "Knobs" rises 240 feet above the general level of the plain, or 275 feet above the Ohio River at Rockport.

The loess.—The hills bordering the plains in the triangular hill land are all covered with loess. The southern border of the northern portion of the hill land is covered from Grandview as far as the point where Lake and Pigeon plains meet. From this point the loess follows the terrace mentioned above northwestward.

The region in the interior, in all the triangular hill land, and for a short distance north of the southern boundary of northern hill land is covered with typical interstream loess.

It follows in all of its details the characteristics of loess as given by Salisbury.[1] It is best developed along the hills bordering stream channels, where it has the peculiar yellow or yellowish buff loess color. Where exposed it weathers into perpendicular banks. As it recedes from the stream channels it becomes thinner and less characteristic. This change in thickness is accompanied by a change in color, so that in the interstream areas it so closely simulates residuary earth that it is impossible to tell where one begins and the other ends. In parts of the deposit, loess-kindchen are very numerous. They are of the same type as those described by Call in Arkansas,[2] which, according to his statement, differs from the typical northern loess-kindchen in being solid. Limonite tubes and concretions and immense numbers of very small land shells occur in some deposits.

The change from typical bluff loess to interstream loess is noticeable in passing northward from the terrace in Pigeon Plain. This peculiarity is of much assistance in working out the origin of the terrace.

The thickness of the loess along the border hills will average about 20 feet. The highest elevation of the loess above the plain is at Rockport, where it rises 110 feet. It was seen at places on the "Knobs" at heights of about 100 feet. In nearly all of the region it extends down to the level of the plains, and much of the plains is made of redeposited loess.

Along the eastern shores of Pigeon Plain this loess is interlaminated with a grayish sand in its lower portions. Along the edge of the hills, and parallel with them, are many lenticular sand hills ranging from 10 to 30 feet high.

[1] Ark. Geol. Survey, 1889, Vol. II, "On the Relationship of the Pleistocene to pre-Pleistocene formations of Cowley's Ridge," pp. 226–228.

[2] Ark. Geol. Survey, 1889, Vol. II, "Cowley's Ridge," by R. ELLSWORTH CALL, p. 38.

The obstructed valleys.—All the valleys which come from the hill region into the plain along the line of hills on the western side of the triangular upland have a very abnormal character. At the points where the streams pass from the upland to the plain, two long ridges of loess and sand 20 to 40 feet high jut out from each side like the arms of a great dam. These two parts almost meet, and the stream passes through the narrow V-shaped space between them. These dams are continuous with the loess-capping of the hills, which is so regular here that it looks much like a great artificial embankment. Although these dams are best developed along this line of hills, a similar tendency to dam the mouths of valleys on the east and south sides of the triangular hill land is shown.

These peculiar loess dams must be taken into consideration in any theory accounting for the manner of deposition of the loess of this region. The fact that valleys have been found facing in all directions, seems opposed to a wind origin. A prevailing southwest wind blowing over dried mud flats in the River and Pigeon plains could have formed all the dams on the western side of the triangular upland, but could not have formed some of the others. For this reason it seems probable that the loess of this region was deposited on the bordering hills as a natural levee by the swollen waters of the river, and that the dams across the mouths of these valleys represent continuations of this levee.

Driven-well area.—In all the plain region bounded by these loess-capped hills, that is, all the River Plain, Lake Plain, and that portion of Pigeon Plain south of the terrace, excepting a very narrow strip in a few places along the base of the hills, wells reveal a great trench filled with an irregular series of clays and water-bearing sands and gravels. This is the region of the driven wells. In the hill region and most of the region in Pigeon Plain north of the terrace all wells strike rock at comparatively shallow depths.

At Rockport wells have been driven 70 feet in the river alluvium without reaching rock. The normal depth of wells in

middle Lake Plain and northern Pigeon Plain south of the terrace ranges from 17 to 40 feet. Very few wells are deeper, and only those near the bordering hills reach rock. One well, 56 feet deep in the narrowest part of Lake Plain, did not reach rock. In River Plain wells range from 30 to 60 feet in depth.

From these wells can be learned something of the original depth of this filled valley. If all sands, clays, and gravels which underlie Lake, River, and a portion of Pigeon plains could be removed, a valley extending at least 56 and probably more than 70 feet below the present plain level, and having its sides of middle carboniferous strata, would be shown.

The old cut-off.—This valley under Lake Plain and the southern part of Pigeon Plain is the same depth as the half filled Ohio gorge of which it is a continuation. It is filled with the same materials. The hills on each side are capped with typical river-bluff loess in the same manner as those on the erosion scarp of the Ohio. The levels of the plain are so nearly the same that a portion of the waters in the flood of 1884 flowed swiftly through Lake Plain and entered Pigeon Plain, where one part followed the terrace and then turned southward and met the other part, which flowed south of Lake P. O., joining the waters of the Ohio again where Pigeon and River plains meet. This stream was four feet deep at the junction of Pigeon and Lake plains.

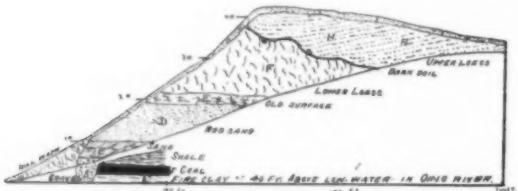
All these facts can lead to but one conclusion: The Ohio River at one time flowed through the Lake Plain and down through Pigeon Plain, entering the Ohio valley again between Enterprise and the eastern border of Warrick county.

To the erosive power of the river is to be attributed the greater part, if not the whole, of the gorge now occupied by that portion of the plain which has been called Lake Plain. In Pigeon Plain the work done was simply deepening and broadening on the eastern side of a broad valley extending from the northeast, which the river entered after cutting through the rock in Lake Plain. A portion of this more ancient valley, extending from the northeast, still remains intact north of the terrace, the terrace being simply the northern boundary of the Ohio's

downcutting in the older valley. The conspicuous differences in width which exist between various parts of the cut-off are to be explained by the fact that the river entered an old river channel when it came to Pigeon Plain. Nearly all the swampy areas mentioned above are simply parts of the old channel which have been but imperfectly filled.

An ancient valley from the north.—The ancient stream plain which the Ohio entered after cutting through the hills two miles east of Lake P. O., is locally called Pigeon valley; but, as has been stated, it is not at present occupied by Little Pigeon Creek. A cross section of the country from *E* to *F*, Fig. 1, shows Little Pigeon Creek in a young, V-shaped, rock-bound valley, separated by a hill of sandstone 30 feet high from the broad old alluvial-filled valley east of it (Fig. 12). Another section running east and west half a mile north of Midway shows the same peculiarities. Well sections in a few places west and northwest of Midway show a depression of 60 feet deep, fielld with blue mud.

Tertiary gravel beds.—Near the base of the hills north of Enterprise (Fig. 1) is a series of sands and gravels. The roads cut through these bounding hills at different places and afford admirable sections of the formations. A section examined along the road running between sections 3 and 4, township 8, south range 7 west, showed the following strata (Fig. 3):[1]



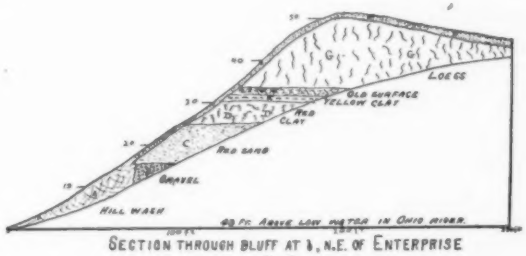
SECTION THROUGH BLUFF AT ■, N.W. OF ENTERPRISE
FIG. 3

		Ft.	In.
A	Hill wash—a reddish sandy clay, - - - - - -	5	0
B	Coarse gravel mixed with sand. The gravel is mostly a much glazed dark yellow chert, but also contains some		

[1] The location of this section is shown at *i* in Fig. 2.

	white quartz and fragments of geodes — largest pebbles from 3 to 4 inches in diameter. A layer of gravel about 3 inches thick stained black with manganese occurs near the base of the part exposed, - - - - - - - -	1	6
C	White, yellow and orange sands cross-bedded. In one place pure white sand is 9 inches thick. Three layers of white sand occur directly above the gravel. The line between the sand and the next stratum D is not well marked, the one grades into the other, - - - - - - - -	3	6
D	Brick red sand, - - - - - - - - - - -	9	0
E	A much stained clay, indicating an old surface, - - - -	2	0
F	A brown loam below turning into a typical loess above full of loess-kindchen - - - - - - - - -	10–15	0
G	A thin layer of dark soil discolored with iron, producing below plates of iron one-eighth of an inch, - - - -	0	3
H	Loess grading into surface humus, - - - - - -	5–10	0
I	Surface humus.		

One mile east of the above the following strata were observed:



SECTION THROUGH BLUFF AT 1, N.E. OF ENTERPRISE
FIG. 4

SECTION 2. (FIG. 4).

		Ft.
A	Hill wash — a reddish sandy clay, - - - - - - - -	10
B	Gravel — coarse, well-rounded yellow chert, with a few white quartz and geode pebbles somewhat stratified. Streaked with manganese, which in places forms a conglomerate, - -	5
C	Reddish sand turning above to reddish clay flecked with white, -	10
D	Very red clay mottled with black, - - - - - - - -	5
E	Yellow to drab clay showing white streaks, - - - - - -	2

IDEAL SECTION FROM A TO B FIG. 1, SHOWING VALLEY OF OHIO AT THE BEGINNING OF THE LAFAYETTE.
FIG. 5

IDEAL SECTION FROM A TO B FIG.1 SHOWING VALLEY OF OHIO AT THE CLOSE OF OZARKIAN UPLIFT
FIG.7

IDEAL SECTION FROM A TO B FIG.1, SHOWING VALLEY OF THE OHIO AT CLOSE OF THE LAFAYETTE.
FIG. 6

PARTIALLY IDEAL SECTION FROM A TO B FIG.1 SHOWING VALLEY OF OHIO AT THE PRESENT TIME
FIG.8

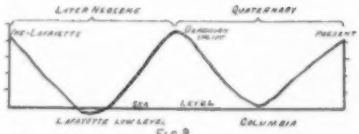
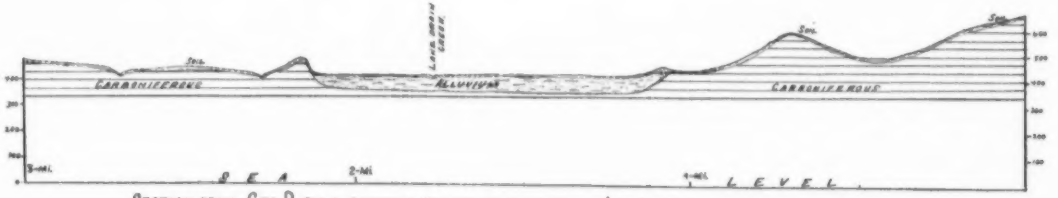


FIG.9
CONTINENTAL OSCILLATIONS OF OHIO VALLEY AT ENTERPRISE



SECTION FROM C TO D FIG.1, SHOWING FILLING OF CHANNEL IN LAKE PLAIN
FIG.10

F Mottled clay much weathered showing yellow, orange and black—evidently an old land surface, - - - - - - - - 3

G Loess containing a few concretions, - - - - - - - - 15

H Surface humus.

One-half mile of section 1 (See *iii*, Fig. 11.) only a thin layer of gravel is found. At this place it is directly overlaid with loess full of concretions. The sands and clays which overlie it in the other sections are absent; but scarcely a quarter of a mile west on the same hill gravels and sands rise 35 feet above the plain (See *iv*, Fig. 11.) and about 70 feet above the river. The gravel here does not appear to be in any particular bed, although it is more abundant near the base of the hill. At times it is found in lenticular beds between the sands. Brick red sands were seen at a height of 35 feet. The pebbles in many places are cemented together, forming large masses of conglomerates. Through the sands are plates of iron as much as 3 inches thick. The old surface was visible but not very well defined.

One mile west of section 1, at *v*, Fig. 11, the following strata were observed:

IDEAL SECTION EAST AND WEST ALONG BLUFFS NORTH OF ENTERPRISE SHOWING UNCONFORMITY AND LOCATION OF SECTIONS DESCRIBED

FIG. 11

SECTION 5. (FIG. 11).

		Ft.
A	Gravel — same as that found in other section. Somewhat bleached, -	20
B	Sandy clay, red flecked with white, - - - - - - - -	4
C	Brown to drab loess, - - - - - - - - - - - -	15
D	Typical loess, - - - - - - - - - - - - -	15

The bipartite character of the loess is clearly shown in section 1, and is also shown, though less clearly, in section 5. The

widespread loess sheets of the southern Indiana and Illinois are considered by Leverett to belong to the Iowan age. This would seem to indicate that the lower loess is Illinoian and the upper Iowan.

By reference to Fig. 1 it will be seen that the sections given above approach very close to the extreme southwest corner of the triangular hill land. Gravel was observed to rise 18 feet above the plain in a hill west of section 5. One-half mile west of this point the hills turn northwest in Pigeon Plain. The height of the gravels in the bluffs northeast of Enterprise would indicate that they could be easily found if they existed in this line of hills trending northeast.

A very careful search, in all available places, failed to discover these gravels anywhere along the old river cut-off, and it seems certain that they do not exist there. If this is the case no considerable breach existed in the line of hills from the southwest corner of the triangular upland to Warrick county, at the time of the deposition of the gravel, else it would have been filled with gravel, and at least some fragment of the deposit would be left. This would seem to show the age of the cut-off; it was cut after the deposition of the gravel.

These gravels and sands have been referred to the later Tertiary for several reasons:

First: The composition of the gravel is such that it cannot be referred to the glacial period; no pebbles of undoubted northern origin being found in the beds. It is obvious that, on account of its nearness to the southern limit of the glaciers, no beds of gravels could have been deposited at this place either during or following the ice-invasion without containing glacial pebbles. The main component of the gravel beds is yellow chert, probably derived from the Lower Carboniferous formations, through which the Ohio passes. The fragments of geodes are doubtless mostly from the St. Louis limestone and Upper Knobstone groups of Indiana. The quartz pebbles must have come either from parts of geodes or the Carboniferous conglomerates or both. As the first ice invasion, in this part of the

country, practically marks the beginning of the Pleistocene these gravel beds must be pre-Pleistocene. That the waters would have brought down glacial gravel, had these beds been deposited during any glacial or interglacial period, is shown by

SECTION FROM E. TO F FIG. 1, SHOWING PIGEON PLAIN AND VALLEY OF LITTLE PIGEON

FIG. 12

the fact that in a recent terrace between Rockport and Grandview several deposits of glacial gravel are found.

Second: The gravel and sand is unconformably overlain by loess (*x* Fig. 11.) In several places an old weathered surface is found between the loess and gravel. It seems probable that the lower loess is Illinoian. This is additional evidence pointing to the conclusion that the gravels are preglacial, for as has just been shown they cannot belong to any glacial or interglacial period.

Third: There is a marked lithological resemblance of these deposits to the lower members of the deposits of gravel in the Jackson Purchase Region of Kentucky. The Kentucky gravels were called "stratified drift" by Loughridge in his report on the Jackson Purchase Region,[1] and were referred to the Quaternary. The lower parts of this stratified drift have since been referred to the Lafayette division of the Neocene by McGee,[2] after two conferences of scientists in one of which Loughridge took part. The gravels also agree lithologically with the Lafayette sands and gravels in other parts of Kentucky as described by McGee.

Fourth: The nonoccurrence of preglacial gravels in Pigeon Plain is without a reasonable doubt and their absence and the presence of typical river-bluff loess along the sides of the valley

[1] Kentucky Geol. Sur. 1888, Jackson Purchase Region, p. 57.

[2] U. S. Geol. Sur., 12th Ann. Rep., 1890–1, p. 500.

point strongly to the conclusion that the cut-off was made between the time of deposition of those deposits; there must, therefore, have been a considerable time interval between the deposition of the gravels and the loess during which this valley was formed.

Fifth: Farther up the river[1] gravels are found on both the Indiana and Kentucky sides. Well sections at Rockport show that river alluvium extends over 70 feet below the level of the river plain. These two facts show that after the partial filling of the valley with gravel the land rose and the river trenched through the gravel and deep into the underlying Carboniferous rocks (Fig. 7). This gorge cutting is correlated with the main gorge cutting of the central part of this country caused by the Ozarkian or Post Lafayette uplift. Hence the gravels are pre-Ozarkian and if instead of taking the first glacial invasion to mark the beginning of the Pleistocene the Ozarkian uplift is taken, the gravels and accompanying deposits are still pre-Pleistocene.

There are these five reasons for believing the gravels and sands to be pre-Pleistocene. Briefly they are:

1. Absence of glacial pebbles in the deposit.
2. Unconformity and old soil between the gravel and the loess.
3. Lithological resemblance of beds to known Tertiary beds.
4. Erosion record furnished by old river channel (?).
5. Pre-Ozarkian deposition of gravel.

Since they are pre-Pleistocene they are here referred to the Lafayette divison of the Neocene because, so far as the writer is aware, they resemble no other pre-Pleistocene deposits.

Fig. 2 gives the location of the Lafayette coast line according to McGee.[2] From the Wabash River northward McGee represents the ocean waters as extending in an indefinite way over southern Illinois. Mr. McGee in speaking of this map says

[1] It is regetted that lack of time prevented the examination of the hills below Owensboro, Ky. For several reasons it is believed that a corresponding series of gravel will be found there.

[2] 12th Ann. Rep. U. S. Geol. Sur. 1890, pp. 353-521.

that the data from which it was made was incomplete in the Mississippi embayment and so the coast line is very general.

If these deposits are Lafayette it would seem that an arm of the sea extended up the Ohio valley from the great Mississippi embayment past Posey, Vanderburg, Warrick, Spencer and into, if not past, Perry county, Indiana. In order to fully establish the size and shape of this embayment it would be necessary to examine carefully all lands bordering the Ohio River on both sides from Perry county, Indiana, to the mouth of the Wabash. Figure 2 shows in a general way this supposed extension of the embayment.

The data collected throws some light on the history of the Ohio valley at this point. This history is shown in Figs. 5, 6, 7, and 8. In these no attempt has been made to show the exact character of the rock bottom of the channel as the well sections furnish no evidence on this point. It may be mentioned, as having some bearing on the history, that a rock shelf comes out from the base of the hills north of Enterprise and extends about 20 feet underground to the present river channel. Just across the river wells are reported 60 feet deep and showing that here as at Rockport there is a deep filled valley.

During the pre-Lafayette period the land stood at about its present level, and the Ohio River cut out the valley shown in Fig. 5. This period was followed by the Lafayette submergence when the sands and gravels were laid down as an estuarine deposit and the valley probably assumed about the appearance shown in Fig. 6.

During the post-Lafayette or Ozarkian period the land stood more than 70 feet higher than now and the river after cutting through the Lafayette sands and gravels cut deep into the underlying Carboniferous rocks (Fig. 7); cutting from side to side it took away the Lafayette gravels in places along the side of the river leaving deposits only here and there. Then followed another subsidence and the river filled up its channel making a broad alluvial flood plain. At some time after the post-Lafayette high level the loess was deposited on the bluffs on either side

making them 15 to 30 feet higher. This gives the valley of the present (Fig. 9).

Figure 9 is a diagrammatic representation of these earth oscillations of the Ohio valley during the Lafayette part of the Neocene and the Pleistocene, the Columbia submergence being based on the supposed aqueous origin of the loess of this region. Only the vertical movement is here represented as no data bearing upon the time covered in each movement was collected.

It should be noticed that this record of continental oscillation agrees very closely with the record of the Mississippi embayment, as given by McGee.[1]

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[1] U. S. Geol. Sur., 12th Ann. Rep., 1890, p. 429.

THE BROWN OR YELLOW LOAM OF NORTH MISSISSIPPI, AND ITS RELATION TO THE NORTHERN DRIFT.[1]

OUTLINE.

I. General characteristics of the Brown or Yellow Loam.

II. Its stratigraphic relations and its distribution in north Mississippi.

A. Its relations to the Lafayette.

Unconformity between the Brown Loam and the Lafayette proper indicated by:

(1) The fact that wherever the Lafayette occurs in force, covered by the loam, the greater part of the present surface relief is due to the irregular contours of the Lafayette, rather than to varying thickness of the former, resulting from recent erosion: topographic relief of the Lafayette greater than that of the Brown Loam.

(2) (*a*) The feathering out of the Lafayette, and its alternate disappearance and reappearance eastward and northeast from Oxford, Miss., thus leaving erosion remnants intercalated between the Brown Loam and pre-Lafayette formations.

(*b*) The presence in the surface formation of northeast Mississippi, where, in many places, the Lafayette is now absent, of materials similar to those of the Lafayette where typically developed.

(3) The degree of oxidation produced in the Lafayette prior to the deposition of the Brown Loam.

(4) The occasional presence of thin patches of a seemingly distinct formation intercalated between the two, composed of materials similar to those of the Lafayette, but unconformable alike with the Lafayette below and with the Brown Loam above, thus indicating, probably, *two erosion intervals* of greater or less duration between the time of the deposition of the Lafayette and that of the Brown Loam.

(5) The character of fossil plants found in bowlders of clay in this intermediate formation, near Oxford, Miss., and derived presumably from the Lafayette.

Summary: The preglacial age of the Lafayette.

B. Its relation to the Loess (or Bluff formation of Hilgard).

III. Origin and age of the Loess Loam.

A. Lower limit of the formation in north Mississippi.

B. Upper limit in the same region.

C. Conditions under which the formation was deposited.

D. Subsequent alteration.

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[1] This paper is based upon a series of personal observations extending continuously from Riverton, Alabama, to Memphis, Tennessee, in a crescentic curve passing

I. GENERAL CHARACTERISTICS OF THE BROWN OR YELLOW LOAM.

The predominant material of the formation in this section to which Hilgard has applied the name of brown loam, or yellow loam is as he states (*Agriculture and Geology of Mississippi*, p. 198), "that of a mellow clay or loam, without any definite structure or cleavage, variously tinged with iron; containing from 10 to 25 per cent., usually, of siliceous sand, the rest being clay mixed with finely divided silica, and forming, therefore, rather loose, mellow soils, and good brick clays.

The loam proper of this formation varies from the brownish-black color of our richest upland soils, where the coloration is due largely to the presence of organic matter through yellow and red, to the grayish-white "buckshot," or "crawfish," lands, which are ill suited to agricultural purposes.

In view of the immense value of these "buckshot" (which characterize the lands of that name by their presence in large number) to the geologist in enabling him to identify with reasonable certainty loams of this period occurring in this region, a brief description of them will not be out of place. They are not confined to the so-called "buckshot" or "crawfish" lands, but

through the counties of Tishomingo, Prentiss, Union, Lee, Pontotoc, Lafayette, Yalobusha, Panola, Tate, Marshall, and De Soto in Mississippi, and Shelby county, Tennessee.

In its preparation invaluable aid has been received from the writings of Hilgard, McGee, Chamberlin, and Salisbury. To my former instructors in field geology, Messrs. A. P. Brigham, H. B. Kümmel, and T. C. Chamberlin, credit is due for valuable training in field methods; to Professors Chamberlin and Salisbury I am also indebted not only for instruction in the theoretical aspects of the science, but for suggestions as well, given both in and out of the class room, bearing upon the subject under discussion; and to Professor Chamberlin I am under special obligations for a critical review of the first draft of this article.

Thanks are also due to Mr. Charles Strong, M.A., former Fellow in Chemistry, University of Mississippi, for a chemical analysis of "buckshot" from the yellow loam; to Dr. F. H. Knowlton, for the identification of fossil plants herein described, and to various others for kindnesses shown me.

But for the collection and collation of data on which this paper is based, and for the conclusions derived therefrom, I alone am responsible. The accompanying photographs were taken by Sanders and Sweeney, Oxford, Mississippi.

are liable to be found, in smaller numbers, wherever the Brown Loam occurs, and one will rarely travel far in the loam region without finding them. They seem to be entirely characteristic of the Brown Loam in this vicinity, not being found in any of the older formations on which it directly rests—that is, as far as my observation extends—and over most of the territory the loam is itself the surface formation. It is true that along streams frequently "second bottoms" are to be found (sometimes as "buckshot" lands), and the more recent alluvial deposits, the latter, however, never containing concretions: but the former are undoubtedly, in many cases, merely terraces of degradation cut in the Brown Loam, when, because of increased velocity due to increase of slope or to decrease of burden, or to both, the streams began to erode the bottoms of their channels more rapidly than their sides, and so ceased to overflow only within the past twenty-five or thirty years.

But it is not always an easy matter in the field to separate the loam from more recent formations. This subject will be more fully treated under the head "Upper Limit in the same Region."

These "buckshot" are usually more or less rounded, yellowish-brown on the oxidized surface, black in the interior, possessing no definite structure, and ranging in size from that of a small shot to that of a small marble. Not infrequently, however, they are much larger, when they usually tend to become more flattened and angular, and are frequently found cemented by iron oxide into a rather friable conglomerate.

These ferruginous concretions have undoubtedly been formed by segregation from the mass of the loam, as have somewhat similar ferruginous concretions and the calcareous nodules from the loess, and especially the friable conglomerate already mentioned, has evidently been cemented *in situ*. (Compare paragraph 338, p. 199, *Agriculture and Geology of Mississippi*.) Typical specimens of the "buckshot" from the loam of Tate county, ground up together and analyzed at my request by Mr. Charles Strong afforded:

	Per cent.
Silica (SiO_2),	78.55
Ferric oxide (Fe_2O_3),	14.88
Water,	1.51
Sulphuric acid (H_2SO_4),	1.03
Lime (CaO),	1.944
Alumina (Al_2O_3),	2.06
Total,	99.974

Perhaps the most notable characteristic of the brown loam is its general disintegrated, "rotten" appearance, with the entire absence of anything simulating stratification in the loam proper, notwithstanding the fact that the particles composing it are usually fine and such as ought, it seems, to have been neatly stratified if deposited under ordinary conditions, and not subjected to subsequent atmospheric and aqueous action. This subject will be more fully discussed under the general head, "Origin and Age of the Loess-Loam."

II. STRATIGRAPHIC RELATIONS AND DISTRIBUTION OF THE BROWN LOAM OF NORTH MISSISSIPPI.

According to Hilgard (*Agriculture and Geology of Mississippi*, pp. 197–198), "the yellow, brown, or reddish loams which have been repeatedly mentioned as forming the surface, and therefore essentially, the soils of the greater portions of the State of Mississippi constitute to all appearance an independent aqueous deposit, posterior to the Orange Sand (Lafayette) and the Bluff formation, and anterior to the alluvial formations of the present epoch. The great thickness which this loam stratum attains in some regions, its distinct definition as well as its comparative independence as to its character of the formations immediately underlying, preclude its being claimed as a mere surface disintegration of the older formations. The nature of its materials and the entire absence of stratification lines distinguish it sufficiently from the Orange Sand where it immediately overlies the latter; while the absence of any large amount of lime, except where it is in immediate contact with strongly calcareous formations, the

presence of a considerable amount of hydrated peroxide of iron as well as the want of proper fossils as distinctly separate it from the Bluff formation of the Mississippi River. . . . .

"From the appearance of the loam stratum, even on high ridges and elevated uplands, it is obvious that its deposition took place, in part at least, anterior to the great denudations which have produced the present surface configuration; nevertheless, its increasing thickness as we approach the immediate valley of the Mississippi shows, as in the case of the Bluff formation, that this great channel was already in existence.

"On the Tombigbee, and on the lower Tallahatchie, Yalobusha, and Big Black, a similar increase in the thickness of the loam stratum may be observed. But on the smaller water courses this is the case only to a very limited extent, showing that, although at the time of the deposition of the loam the channels were already more or less impressed upon the surface and high ridges existed which remained above the level of the water which deposited the loam, the minor denudations which have caused the present undulating surface had as yet exerted but little influence. The lines of contact between the Orange Sand and Loam, where the latter is evidently *in situ*, are generally much less undulating than are those between the Orange Sand and the older formations."

A. *Relation of the Brown Loam to the Lafayette.*— From the foregoing account, it would appear that the Brown or Yellow Loam proper is a formation *sui generis*, deposited on a previously eroded land surface in such wise as not to turn aside the larger preëxistent streams, and distinguished from the Lafayette only by "the nature of its materials, and the entire absence of stratification lines where it immediately overlies the latter." These criteria for the discrimination of the Brown Loam and the Lafayette will, of course, fail of application (1) where there is no great difference in the nature of the materials of the two formations, as is frequently the case, especially near their line of contact, and (2) where the upper part of the Lafayette, as well as the Brown Loam, is unstratified.

Wherever the loam attains a thickness of 10 or 12 feet—and it is rarely thinner than this for any considerable distance—it is usually not difficult to identify it, especially its upper portion, but, as Hilgard has long ago pointed out, this formation is frequently so modified by underlying terranes as to render its delimitation in those places a matter of great difficulty, if not impossible. For instance, locally the characteristic loam may be replaced by sand variously colored; and when all traces of stratification, if they ever existed, have become obliterated through the action of percolating chalybeate waters, which both color and cement the sand grains, and when this red, sandy phase of the "Brown Loam" or "Yellow Loam" rests directly upon similar sands of the Lafayette—whence the former have generally been derived—it frequently becomes a matter of impossibility to draw any certain line between the two. This is often the case in the "red lands" of the Pontotoc Ridge and its northward continuation, the "Buncombe Hills." However, judging from an exposure near the depot in the town of Pontotoc, and from numerous other sections on the ridge, both the brown loam and the Lafayette seem to be represented in the Pontotoc Ridge; but as we shall presently see, the Lafayette is frequently absent in northeast Mississippi, the Brown Loam resting directly upon still older formations.

A section in the cut on the Illinois Central Railroad just south of the depot at Oxford shows typical loam at the top, grading into rotten or friable clay, which, becoming more sandy below, passes insensibly into a semi-indurate, massive red sandstone. The base of the section here shows nicely stratified sands and clays, presumably of Lafayette age, though possibly later, but no definite line can be drawn between the two formations at this exact point.

While we cannot always with certainty determine, in the field, the limits of the two formations, and while there are to be found places of seeming local conformity, which we should naturally expect, still the two can generally be separated without difficulty, because, when typically developed, the two forma-

tions possess little in common. And from such good exposures I have obtained strong evidence of great and widespread unconformity between the Brown Loam and all older formations. A great erosion interval is indicated by the following facts:

1. A considerable interval of erosion between the Lafayette and the Brown Loam periods is indicated by the fact that wherever the two occur in force the greater part of the present surface relief is due to the irregular contours of the Lafayette rather than to varying thickness of the post-Lafayette resulting from recent erosion. In other words, the topographic relief is greater in the Lafayette than in the post-Lafayette. This is indicated by the greater thickness of the post-Lafayette in existing valleys than on hilltops, even where there has been no recent deposition in the former of loam washed in from the hills. Many Lafayette hilltops, frequently capped with ferruginous sandstone bowlders, seem to have been above water continuously since Lafayette times. It seems that the land in this region has not been under water long enough since the period of Lafayette erosion to allow the complete filling in of the channels cut in the Lafayette; and this is partly due to the fact that deposition was taking place simultaneously, though not to so great an extent, over the greater part of the hills and ridges into which the Lafayette had been cut. And so the most of our present streams, especially the larger ones, are of the superimposed type—superimposed by sedimentation.

The greater deposit of sediment in the valleys is probably due to the fact that the valleys were submerged for a longer time, but partly also to the greater effect of their deeper waters in the checking of currents and consequent precipitation of sediments.

2. Another line of evidence of unconformity between the Lafayette and the Brown Loam, closely related to the one just given, lies in the fact that the Lafayette frequently feathers out, leaving the Brown Loam to rest directly upon the formations older than the Lafayette. Sometimes the evidence of the former extension of the Lafayette over the area in question is not con-

clusive, as where the Brown Loam rests directly upon the pre-Lafayette formations, and there is no trace of the Lafayette left in the vicinity, it is impracticable under such circumstances to say whether the Lafayette once covered the given locality and has been entirely removed by erosion, or whether it was never present. Such a state of things is exhibited in many places in the country near New Albany, Miss., and elsewhere. The Brown Loam mantles the hills and dales of this region, resting in many places directly upon the Cretaceous, sometimes upon the Lafayette, as it does elsewhere (as we shall presently see) upon the Lignitic Tertiary, and as it does regularly upon the Lafayette further westward. It cannot be a surface disintegration of the Cretaceous at this place; but it is seen to be directly continuous with the loam stratum elsewhere observed, and was without doubt formed at the same time and in the same way. (As to the geological relations of the surface soil, Brown Loam, in this region, see also *Ag. & Geol. of Miss.*, paragraphs 335, 336, and 337, pp. 198–199.)

But sometimes the Brown Loam rests upon older formations once covered by the Lafayette, which has subsequently been removed by erosion. There are two lines of evidence: (*a*) Near Oxford, Miss., where the Lafayette is typically developed, it attains a maximum thickness of something like 200 feet. But towards the east it soon thins out, exposures of the Lignitic being quite common within eight or ten miles of Oxford.

As the region of Flatwoods is approached, the Lafayette becomes discontinuous, and patches of it only are to be found intercalated between the Brown Loam and the Northern Lignitic. The Lafayette seems to give out altogether several miles before the Flatwoods are reached. At the exact western limit of the Flatwoods, some ten miles west of Pontotoc, on the Pontotoc and Lafayette Springs road, several feet of typical brown loam are seen to rest directly upon the blue clays of the Lignitic. Over the Flatwoods region, here six or seven miles wide, both the Brown Loam and the Lafayette are usually absent, the latter always, the former occurring in limited patches towards its east-

ern border. Both formations seem to be found again in the Pontotoc Ridge and Buncombe Hills, as already noted; but the Lafayette soon gives out and seems not to appear again, at least not strongly and typically developed. For example, over the greater part of Union, Prentiss, and Tishomingo counties, the Brown Loam rests upon formations older than the Lafayette. Frequently the Brown Loam has been removed by erosion, and the "Rotten" Limestone, Selma, or Tombigbee Chalk comes to the surface. Exposures of this latter formation are quite common in the prairie region, as is well shown around Booneville, Baldwyn, Marietta Springs, etc.

On a hilltop about fourteen miles from Booneville and sixteen miles from Iuka, on the old Booneville and Iuka road, several feet of Yellow Loam repose directly upon stratified, blue, pyritiferous clay of the Eutaw (?) group.

At Bay Springs, in southwest Tishomingo county, the Brown Loam rests either directly upon Sub-Carboniferous sandstone or there is a thin intervening stratum of pyritiferous Eutaw (?) clay — the source of the chalybeate waters of the springs. (*b*) While there is plenty of orange-colored sand in east Prentiss and in west Tishomingo counties, nowhere in this region did we find materials of undoubted Lafayette age *in situ*, though it seems likely that the Lafayette once covered this area, and that small patches of erosion remnants may still exist, because materials similar to those found in the Lafayette further west are here found to a greater or less extent scattered irregularly through the Brown Loam. The quartzose pebbles of Tishomingo county, for example, described by Hilgard (*Ag. & Geol. of Miss.*, 1860), and referred to the Lafayette epoch, seem to occupy an entirely different stratigraphic position from the majority of those in the western region, *i. e.*, from Memphis, Tenn., to Grenada, Miss., and southward, which are evidently of Lafayette age. In the former region these pebbles are found intermingled with the Brown Loam, as shown in many places near Iuka and elsewhere, while in the latter region they are invariably below the Brown Loam, sometimes in apparent local con-

formity with its base, elsewhere well within the Lafayette The gravels of this western belt were all evidently first transported to this region and deposited during the Lafayette epoch, and towards its close, though in many places they have been subsequently moved locally and redeposited at the base of the brown loam. On the principle of homogeny, the gravels of the eastern belt are thought to have been brought down originally at the same time with, and in the same manner, as those of the western region; but owing to the complete, or almost complete, removal by erosion of the Lafayette in the eastern region, these gravels have been shifted from their original positions and redeposited within the Brown Loam, and by the same waters (for I hold the Brown Loam to be essentially an aqueous deposit) which deposited the finer materials of the brown loam. These waters need not have been swift in order to transport pebbles, for these were probably only locally shifted and let down from higher to lower levels. On the other hand, the fineness of the materials of the bulk of this formation gives evidence that the formation, as a whole, was deposited by sluggish currents overloaded with fine sediment.

And so an application of the principles of homogeny, as defined by McGee (*12th Ann. Rep. U. S. Geol. Surv.*, p. 381 *et seq.*) to the Brown Loam of the whole of north Mississippi, together with the fact that undoubted erosion remnants of the Lafayette are to be found as far east as the Pontotoc Ridge, would seem to demand the former extension of the Lafayette over the whole of the area in question. A comparison of the hypsographic distribution of existing patches of the Lafayette with the hydrography of the region strengthens this conclusion, since remnants of the Lafayette are to be found on the highest hills, while on lower lands near by, the Lafayette may be entirely absent. As to the original thickness of the Lafayette, we have no way of determining this; but the evidence, direct and indirect, just presented, indicates a considerable erosion interval between the Lafayette and the Brown Loam during which a large part of the former had been removed prior to the deposition of the latter.

3. The degree of oxidation and attendant phenomena produced in the Lafayette prior to the deposition of the Yellow Loam, by atmospheric and aqueous agencies, likewise tell the story of a considerable interval of chemical as well as mechanical erosion between the periods represented by these two formamations. (See *Am. Jour. Sci.*, Vol. XLI, p. 370.)

4. The facts already presented show conclusively that a long period of erosion intervened between the time of deposition of the Lafayette and that of the Yellow Loam. Over most of the area embraced within the scope of this paper the Lafayette seems to be essentially a continuous deposit, with the Yellow Loam resting directly and unconformably upon it, although its irregular stratification and the alternating layers of coarser and finer material indicate varying local conditions such as would result if the formation were deposited in the manner supposed by Hilgard.

McGee finds evidence in some localities of a twofold and even of a threefold division of the Lafayette, the divisions being separated by "pseudo-unconformities," which, according to him, represent only local shifting of currents, and consequent change in deposition, and do not mark the limits of distinct episodes. (*12th Ann. Rep. U. S. Geol. Surv.*, pp. 453–456, and elsewhere.)

But sections observed by the writer have caused him to doubt the unity of the Lafayette, as now defined in its type locality, and to raise the question whether the uppermost member of the Lafayette may not represent a distinct formation.

Occasionally there is found a stratum of clay and sand, or of clay alone, intercalated between the main bulk of the Lafayette and the Yellow Loam, and sharply separated from both by irregular or billowy erosion lines. This deposit is usually only a few feet in thickness, and consists, (*a*) of compactly bedded pipe clay, (*b*) of interlaminated clay and sand (the different layers sometimes quite thin, sometimes several inches thick), or (*c*) of a heterogeneous, unsorted mixture of sand and clay bowlders of various shapes and dimensions, resembling very much in physical characteristics, the unsorted till of the North.

An excellent illustration of the first is found in an exposure of some thirty or thirty-five feet, four and one-half miles south of Chulahoma, Marshall county, Mississippi. Here we find several feet of compactly bedded pipe clay, with a billowy upper surface, covered by eight or ten feet of Yellow Loam — from which it is quite sharply separated—and resting upon a decidedly eroded surface of cross laminated Lafayette sand. The three formations are distinctly traceable for perhaps a hundred yards, when the surface of the Lafayette descends so far as to be no longer exposed. Stratigraphically and lithologically the three formations are here very distinct, and show no evidence whatever of grading into one another. The erosion line between the clay and the sand is as sharply defined as that between the clay and the Yellow Loam. This clay, moreover, gives evidence, in its irregular streakings of ferric oxide, of having once been highly fossiliferous, and this evidence is strengthened by the fact that it still contains a few leaves in a fine state of preservation. These fossils were evidently formed *in situ* and not plucked from older formations and redeposited. Not enough were found to be of any practical value in determining the geological age of the clay stratum in which they occur, and those found have not been identified. Of the specimens in my collection at least two distinct species are represented, the one having a very small netted veined, linear-oblong leaf, resembling a willow leaf, or the leaf of a water oak, the other also netted veined, oblong-ovate, and entire, but much larger than the first, being about an inch broad by two and a half inches in length. If the formation in question belongs to the Lafayette, then the Lafayette here contains fossils of its own in its upper part; but it appears to belong to a distinct epoch or episode, and the presence of fossils in clay would seem to indicate conditions of deposition different from those which appear to have obtained when the Lafayette sand, directly underneath, was being deposited.

The accompanying photographs represent a continuous section one-third of a mile north of the depot at Oxford, Mississippi. A cut in the Illinois Central Railroad at this place, giv-

ing an exposure of thirty to thirty-five feet, shows a section very similar to the one just described, except that the middle member here consists of eight to twelve feet of clay bowlders, large and small, rounded and angular, mixed indiscriminately with sand. This section shows:

FIG. 1.—Section near the depot at Oxford, Mississippi, showing two members of the Columbia Formation and their relation to the Lafayette. (*a*) Yellow Loam; (*b*) fossiliferous clay bowlders and sand; (*c*) cross-laminated Lafayette Sand.

(*a*) At top, 0–8 feet of Yellow Loam.

(*b*) 8–12 feet of clay bowlders and sand.

(*c*) At base, 0–12 feet of cross stratified Lafayette sand.

Here the three formations are very distinct lithologically, and there is no evidence of the gradation of one into another either in a lateral or in a vertical direction.

The top stratum (*a*) is a typical loam, while (*b*) consists of sand mixed with clay bowlders, rounded and angular, varying in size from mere pellets up to slabs one to two feet thick, four to six feet long, and of unknown width, but presumably of not

more than a few feet. The lowest stratum (*c*) has been sufficiently described above.

This bowlder stratum (*b*) consists of rock materials similar to those of the directly underlying or adjacent Lafayette; so from a lithological standpoint two views of the origin of this stratum are possible. Either it and (*c*) have been derived from the same pre-Lafayette formation, or formations, and the apparent unconformity between them is to be regarded as a "pseudo-unconformity," as explained by McGee, or the two are distinct formations, and the upper one has been derived from the lower.

The latter I regard as the more probable for the following reasons:

1. The extent to which the underlying sands have been eroded, and the very abrupt change from cross laminated sands (seemingly a local delta deposit) underneath, to a bowlder stratum of the character described—these seem to indicate extraordinary conditions of deposition for the bowlder stratum, and an amount of erosion of the underlying formation, which could not be accounted for by a mere local shifting of currents, with no appreciable changes of level nor consequent interval of erosion.

Smaller clay pellets, it is true, occur quite frequently elsewhere, in the body of the Lafayette, but never so large, as far as I am aware, as those just described.

2. The size of many of these bowlders, and their frequent angularity (which may be due in part, however, to subsequent atmospheric action), as well as their composition and physical texture, render it highly improbable that they have been transported by running water for any considerable distance.

The Lafayette proper is about 150 to 180 feet thick in this vicinity, as shown by recent well borings; and the Lignitic, the immediately underlying deposit, comes to the surface only at a distance of several miles to the eastward. A well recently bored upon the university campus, after passing through a few feet of surface loam penetrated the Lafayette formation, and

fossiliferous clay bowlders from (*c*).

FIG. 2.—Northward continuation of Fig. 1. (*a*) here removed from center of photograph by erosion. Talus at base composed largely of fossiliferous clay bowlders from (*b*).

reached the Lignitic beds at a depth of about 180 feet. Wells in Oxford struck the same beds at depths of 155 to 160 feet.

The pipe clay of which these bowlders are composed is also of an unctuous, kaolinic nature, such as would not seem able to suffer prolonged transportation by running water without disintegration.

3. The clays of this bowlder stratum are altogether unlike those of the Lignitic beds near here, which are generally blue, or black, pyritiferous, and friable when dry. But the clays, also, of the Lafayette proper, which must have come from a distance, show a like dissimilarity to the Lignitic clays, having become altered probably in color and relieved largely of carbonaceous matter and of iron pyrites (if they came from the Lignitic) during transportation or subsequent to their redeposition. So the argument based on the dissimilarity of the clay bowlders to clays of pre-Lafayette age in this vicinity is of no value considered apart from the conditions under which they must have been deposited, and the short distance to which they could have been transported by running water.

4. These bowlders are frequently highly fossiliferous, containing plant specimens preserved in ferric oxide, and prolonged water transportation, if possible, would probably have defossilized them by the removal of the iron oxide in solution. The fact that no well-defined fossils peculiar to itself have yet been found in the Lafayette might be adduced as evidence that these fossiliferous bowlders must have come from some other source (and the character of the fossils as described by Dr. Knowlton would seem possibly to indicate their derivation from an earlier formation); but this does not necessarily follow, since plants must have existed during the Lafayette, and if none have been found in it the explanation is probably to be found in the fact that its materials, as a rule, are not well adapted to the preservation of organic remains. Its clays, moreover, as already pointed out, are very similar to those of the stratum under discussion, and the latter are very rarely fossiliferous. It is only occasionally that we find fossils in compact, close-textured, impermeable and

highly colored clays. Where there has been freer circulation of water, and where roots of recent plants have penetrated them, these clays have become more friable and partially decolorized, the change from their former condition being indicated, as already noted, by the peculiar distribution of the remaining ferric oxide, which frequently retains the shape of stems and leaves but not their texture. And in many instances such markings are traceable by the lighter color and by the more disintegrated condition of the clay where fossils seem to have existed, the ferric oxide having been, it seems, more completely removed, subsequently, than from the surrounding clay. Much care, however, is needed in the interpretation of many of these tracings, part of which are due to the action of roots of recent plants, part to the collection of ferric oxide on slickenside surfaces resulting from the jointing of the clay and the scratching of joint surfaces by their movement over sand grains. Such markings frequently give a fluted appearance resembling very much the impressions of parallel veined leaves.

The foregoing considerations, it seems to me, render it highly improbable that the coarser and clayey materials of this peculiar bowlder conglomerate could have been transported for the distance of several miles by running water.

The peculiar admixture of sand with clay bowlders, large and small, rounded and angular, with no trace of sorting, suggests to the writer the possibility of this deposit having been formed after a partial reëlevation succeeding the Lafayette subsidence, by the sapping of the banks of a small post-Lafayette lake or stream.

The inability to discover similar plant remains in the adjacent Lafayette might be explained by the removal of the original beds by plantation.

It is barely possible that this particular deposit may have been made by floating ice during the first interglacial epoch (or more probably during the first interglacial episode of the first glacial epoch), and I shall present, later, evidence of iceberg action at this time, in this vicinity — but the elevation of

this deposit above the larger water courses, such as the Tallahatchie and Yocona rivers, between which it lies and down whose swifter waters most of the icebergs probably traveled, renders it hardly probable that the deposit was formed in this way.

According to Professor Chamberlin the Natchez formation occupies similar relations to the Lafayette and to the Loess of the northern Mississippi, though it contains crystalline pebbles in addition to materials derived from the Lafayette; and he suggests that both may have been formed at the same time, the two representing a distinct episode, or epoch, between the Lafayette and yellow loam.

On this hypothesis there was a period of upheaval succeeding the Lafayette deposition, during which all formations then existing were greatly eroded. This was followed by subsidence in the region of the lower Mississippi, accompanied by the deposition of the Natchez formation and of the stratum between the Lafayette proper and the Yellow Loam in this vicinity. Then followed an interval of upheaval and erosion, marked by the irregular contours of the upper surface of the bowlder stratum of the Oxford section and by the presence of an old soil at the summit of the Natchez formation. It is not to be understood, however, that the supposed Natchez subsidence was great enough to submerge the areas in question below sea level, for the deposits have not the characteristics and distribution which would probably have resulted from the action of ocean waves.

The deposits were probably formed when the land surface was at a comparative base level, and are of fluvial and lacustrine origin, and not marine, nor even estuarine. The amount of geological time represented by this hypothetical oscillation (during which the Natchez formation and its supposed congener in this vicinity were deposited and subsequently eroded prior to the deposition of the Loess and the Brown Loam) is probably very short, though it serves to emphasize the time interval between the Lafayette and the Brown Loam.

5. Other evidence bearing on the age of the Lafayette, and

therefore upon that of the Yellow Loam, is that furnished by the character of fossil plants found in the bowlder bed at Oxford previously described. The value of this evidence, however, is diminished by the fact that it is not absolutely certain that they came from the Lafayette formation. These fossils are mainly leaves and small stems, and occasionally an acorn (?), of what "seems to be a new and very fine species of Quercus" (Knowlton); and sometimes there is found a specimen of a palm, that "is with little doubt Flabellaria Florissanti, Lx, found originally in the Eocene of Colorado" (Knowlton). The preserving agent is apparently red hematite which shows up the smallest veinlets of the leaves. Indistinct traces of grass-like plants are also to be found. In answer to inquiries as to the probable age of these fossils, as referred to the accepted geological time scale, and the probable climatic conditions then prevailing, as indicated by the nature of the plants, Dr. Knowlton has this to say: "The data upon which to base an opinion of age is, as you see, quite too scant for a positive assertion. I should say, however, that it indicated rather an Eo-Lignitic than later age. Could it be possible that the clay in which the plants occur was a pocket or lens which had been torn from the Eo-Lignitic and redeposited in the Lafayette? However, I incline to the opinion that they are Eocene rather than later, but more material will be needed to confirm or disprove this .... the above mentioned plants do not indicate any marked change from the climate of the present day .... I imagine that when the fossil flora is thoroughly studied we shall find that species or forms have persisted for long periods of time with comparatively little change."

This paper deals with the study of the Lafayette formation only to the extent necessary for fixing the lower limit of the Yellow Loam. And the foregoing evidence of unconformity between the two is adduced in corroboration of the evidence presented by Chamberlin and Salisbury (*Am. Jour. Sci.* Vol. XLI, p. 359 *et seq.*) in favor of the preglacial age of the Lafayette. The proof of the glacial age of the Loess of the Missis-

sippi valley, presented by them in the article just referred to, appears conclusive.

I have shown that the Yellow Loam occupies the same position with reference to the Lafayette in the interior, that the Loess does along the Mississippi valley. By the foregoing considerations, and by a review of the relation of the Yellow Loam to this loess in this vicinity, I hope to strengthen the evidence already presented by McGee that the Yellow Loam and the Loess are not only homotoxial but that they are also genetically related.

B. *The relation of the Brown or Yellow Loam to the Loess (or Bluff formation of Hilgard).*— These two deposits were discriminated by Hilgard, who considered them as separate formations, the Brown Loam being the younger (*Ag. & Geol. of Miss.* 1860).

Later, McGee and others have noted the somewhat complex relations of the two along the bluffs of the southern Mississippi, especially around Vicksburg and Natchez (*12th Ann. Rept. U. S. Geol. Surv.*, p. 392 *et seq.*).

The present paper has nothing to do, except in a very general way, with this area, concerning which McGee says: "The loess of the lower Mississippi region may be characterized as a peculiar condition of the Brown Loam, or as an imperfectly demarked phase of the great formation into which both deposits fall." Having reached the same conclusion from a study of the area embraced within the scope of this paper I shall now proceed to state the grounds on which this opinion is based:

1. The Drift of the North is the surface formation, to which the loess of the river valleys bears an ascertained and definite relation, as already noted. During the Glacial period there were extensive continental oscillations during which, according to some authorities, the whole southern part of our continent was submerged: so, on *a priori* grounds, we should find as the "southern equivalent of the northern Drift" a mass of water-deposited sediment more commensurate in quantity with the Drift than is the Loess alone. Evidence of such submergence will be brought out in the further discussion of this subject.

2. Having traced the surface formations from Bear Creek, on the Alabama-Mississippi-Tennessee lines, to the Mississippi River at Memphis, and to the "bluffs," 40–50 miles below, I found the loess and the loam to be absolutely continuous, the former usually being absent, or not characteristically developed, except within a few miles at most of the existing "bluffs" and frequently in the "bluffs" themselves replaced entirely, locally, by loam, with characteristic ferruginous "buckshot," to the very base.

The following characteristic sections will serve for illustrations:

A. *Sections at Memphis, Tenn.*—(*a*) Bluff just north of Custom House; at base, typical bluff-colored loess, non-effervescent throughout its mass, but containing characteristic concretions, calcareous and ferruginous, — the latter tubular or cylindrical rather than rounded — and obscure fossils. This passes laterally into yellow or brown loam, and also becomes loamy at the top — as the loess quite frequently does. Evidently the loam here is only modified loess, or the latter is only a peculiar phase of the loam. This is the most characteristic exposure of the loess observed at Memphis. Going down the river both fossils and concretions (of the loess proper) become less frequent. (*b*) Section about one-half mile north of the river bridge; 60–70 feet (estimated) of typical brown loam with its characteristic "buckshot" to the very water's edge, where it rests unconformably on the Lafayette — the loess being entirely absent. Exposures near here show a loess-like loam devoid of fossils and concretions. (*c*) Section about one-third mile north of river bridge. (1) At top 60–70 feet of loam. (2) White and reddish sand, cross laminated, and containing occasional pebbles, sometimes stratified, 10 feet. (3) Stratified Lafayette gravel, 2–3 feet exposed. The lowest 5 or 6 feet of (1) are pronouncedly sandy, the upper part of (2) humus stained, indicating an old soil. (*d*) Section about 30 yards south of the last. Here we have about 60 feet of yellow loam, with "buckshot" at its very base, resting directly upon stratified

Lafayette gravel, No. (2) of the preceding section being absent.

B. *The relations of the Loess and the Brown Loam along the "bluffs" of southwest Tate and northwest Panola counties.*— In this region the bluff is much higher, though far less precipitous than at Memphis, where it is being continuously washed at its base. The estimated height of the rampart at Askew's Bluff, northwest Panola, is 200 feet. But thence it diminishes in altitude both northward and southward. Concretions and fossils are generally to be found in abundance within a few hundred yards eastward from the present base of the rampart in this region, but no clear cut section showed in any one place the characteristics and the relations of the Loess from the top down to the Lafayette. However, a continuous, descending section from the summit of Askew's Bluff passes over several feet of gravels, similar to those at Memphis and southward, about two-thirds of the way down. Further down, the blue clays of the Lignitic are struck and something like 40 or 50 feet are exposed; and one-quarter mile north, in a ravine, there is found a seam of cheesy lignite one or two feet thick. Traced eastward from this point the loess passes insensibly into the surface loam. The main body of the Loess here, as elsewhere, is as a rule, less disintegrated than the Yellow Loam; but the formation is apt to be more loam-like at the top, where most exposed to atmospheric action.

Traced northward the Loess seems to maintain its typical character as far as studied, *i. e.*, to the road running west from Senatobia. Proceeding eastward along this road from the bluff, here quite low, the shells soon disappear from the Loess, but limestone concretions were found as far as four or five miles from the foot of the bluff, at a point one mile east of Strayhorn. Between these two places the Loess frequently alternates with loam, and at one place, about one and one-half miles west of Strayhorn, limestone concretions and ferruginous "buckshot" were found associated together in a sort of loess-loam, which became more loamy at the top. Here, as frequently, the limestone concretions assume dendritic forms, caused evidently by

percolating calcareous waters in ramifying crevices. Specimens were taken from such crevices.

No microscopic examination of the loam was made for comparison of its mineralogical constituents with those of the loess; but owing to a greater degree of subsequent alteration in the former it seems doubtful whether such tests when made would prove entirely satisfactory. The chemical composition of the two, in their typical development, seems to differ rather in degree than in kind, from the same cause, and the two pass into each other by insensible gradations.

From the foregoing it would appear that, if my observations be accurate, the Brown Loam and the Loess of this region are not only homotaxial but synchronous as well.

III. ORIGIN AND AGE OF THE LOESS LOAM.

The Loess of the north has been distinguished as belonging to two separate epochs, and a similar twofold division of the same in the south is mentioned as a probability by Chamberlin and Salisbury, in an article entitled "On the Relationship of Pleistocene to the pre-Pleistocene formations of the Mississippi Basin, south of the limit of glaciation" (*Am. Jour. Sci.*, Vol. XLI). The Yellow Loam is here considered as the interfluvial equivalent of the Loess, but the writer has seen nothing to suggest, or which would justify, the division of the former into two or more parts, separated by a time interval of greater or less duration. On the other hand, sedimentation generally seems to have been continuous from the beginning to the close of the period —the first deposits, frequently composed mainly of local and coarser materials, being directly followed by the finer deposits which constitute the main bulk of the formation. It does not follow that the Yellow Loam formation may not be of a bipartite nature elsewhere; and if it should prove universally indivisible this need not antagonize the idea of a twofold division of the Loess, because owing to elevation, or other causes, there may have been no interstream deposit here contemporaneous with one epoch or the other of the Loess, the deposition of which seems

to have been confined to the vicinity of the river courses at that time.

I may call attention, however, to the fact that in section *c* of the bluff at Memphis, as previously described, a humus stained horizon, indicating an old soil, was found at the upper surface of number 2, but this seemed to me to be the upper surface of the Lafayette, and not a part of the Loess-Loam at that place.

Because of the evident twofold division of the Loess in the north we should naturally expect the same for the Loess in the south, and perhaps for its interfluvial equivalent, the yellow or brownish surface loams. But this does not necessarily follow, for reasons stated above, and the results of my observations, considered without regard to exposures which I have never seen in other localities, will not justify me in an attempt to subdivide the Loess-Loam formation of this region. The formation is, therefore, considered in its entirety and the question of its delimitation discussed more fully in the following paragraphs.

A. *Lower limit of the Loess-Loam.*—This subject has already been discussed more or less fully in the description of the stratigraphic relations of the Brown Loam. The first Glacial epoch is divided by Chamberlin and Salisbury (*Am. Jour. Sci.*, Vol. XLI, pp. 362–363) into two episodes, and the inferior member of the Loess is referred to the close of the second Glacial episode of the first Glacial epoch. From the foregoing evidence it will be seen that the Brown Loam cannot be earlier, and that it is the interfluvial equivalent of at least one, perhaps of both, divisions of the Loess. And neither seems to be the full representative, in the South, of the northern Drift. The Natchez formation was probably deposited during the first Glacial episode of the first Glacial epoch, and towards its close, and I have given reasons above for believing that the same episode is represented in north Mississippi by scattered patches of subaërial deposits. These deposits, as already noted, are composed of local material, and while they may be contemporaneous with the earlier Drift, they are not genetically related to it, as the Natchez formation along the river is said to be.

The Brown Loam and its substratum in many places in this vicinity show a remarkable similarity to the Columbia formation of McGee as described at its type locality. Yet the facts recited above suggest that perhaps the Pleistocene history of the lower Mississippi may not be so simple as he has pictured it. But it is important to note, in this connection, that evidence of a distinct episode between the Lafayette and the Brown Loam is confined to the more inland and higher counties, such as Marshall and Lafayette. Further west such a deposit, if it ever existed, has been removed, and here, too, the Lafayette if it were ever thick has been almost entirely removed, leaving only a few feet of gravel and sand between the Loess and the Lignitic beds, as is the case at Askew's Bluff, Panola county. In the bluff at Vicksburg, too, in some places, only a few feet of such gravel intervene between the Loess and the Vicksburg limestone of the Tertiary.

Relation of the gravel deposits of north Mississippi to the Loess-Loam.—These gravels, in the main, are considered as primarily belonging to the Lafayette, but in many places they seem to have been worked over and redeposited in the Loess-Loam, or at its base, near their original location. The difference in the stratigraphic position of the pebbles of the eastern and western belts has already been noticed. In the former region, most, if not all, the pebbles have been worked over. These also contain a much higher percentage of chert pebbles—sometimes quite large and angular, or subangular—derived from adjacent Sub-Carbonifereous chert deposits.

The gravels of the western belt are found most frequently at the base of the Loam or Loess. Generally it is not practicable to determine whether they belong to the Loam (or Loess), or whether to the top of the Lafayette. But occasionally a few feet of Lafayette sand intervenes between the gravel bed and the surface formation. At the Memphis bluff, as we have seen, the gravels belong undoubtedly to the Lafayette. At a point eleven miles from Batesville, on the Batesville and Water Valley road, the following relations were observed: A hill mantled

with several feet of loam, which becomes thicker down the hillside and in the adjacent valley; near the hilltop the underlying Lafayette sands contain scattered quartz pebbles, while further down the hill, at a considerably lower level there is a well-defined pebble stratum at the base of the loam. Toward the hilltop the pebbles are evidently well within the Lafayette, while toward the bottom of the hill the pebble stratum seems to form the basal member of the Loam, though it is undoubtedly derived from the higher level gravel of the Lafayette (compare the relations of the Loess to certain gravels in southern Illinois *Am. Jour. Sci.*, Vol. XLI, p. 366 *et seq.*).

Similar gravels have been described by Professor Salisbury (Jour. Geol., Vol. III, pp. 655–667), from Devil's Lake, Wisconsin, where they underlie the Drift. They are therefore of Pre-Glacial age. Direct correlation of this deposit with the southern gravels is at present impossible, but it seems probable that both were laid down by the same "definitely limited set of agencies" acting within "a definitely limited period of time"—a period closed by the inauguration of the Glacial period in the North.

As to the conditions under which the Lafayette was deposited, I do not feel prepared to speak. However, it seems to me that Hilgard's view as stated in "The Age and Origin of the Lafayette Formation" (*Am. Jour. Sci.*, No. 257, Vol. XLIII), on the whole, is to be preferred; only we must look to another source than melting continental glaciers, for the floods which brought down and deposited the materials of the Lafayette.

B. *Upper limit of the Loess-Loam.*— This formation covers by far the greater part of the surface in this region, and it is only in the "second bottoms" and in the bottoms proper that we find materials of a possibly later age. Many of these "second bottoms" are simply low, broad terraces of degradation carved out of the Yellow Loam, as already noticed. Others are probably stream terraces of constructive origin. But as such deposits are confined to the vicinity of streams, deposition along streams proceeding *pari passu* with erosion of the general surface of the country; and because the materials of such terraces

have been derived wholly or largely from the Loess-Loam, and both formations being usually unstratified, we have no certain means of discriminating the two. And, indeed, the necessity for such discrimination seems very slight when we remember that the formation of these stream terraces began immediately after, or coincidently with, the general uprising which brought the Loess-Loam period to a close; and that they are local lowland deposits formed during a period of general elevation and erosion, rather than general deposits formed during a period of depression. The important point to remember is that the whole of the area under discussion has never been under water since the period of depression during which the Loess-Loam was deposited, and that the interval of general erosion, and "loss of record," which has existed here since the deposition of the Loess-Loam is represented by the contemporaneous deposits of lakes, streams, and adjacent shore lines. Geological history written on tablets of ocean bottom is comparatively easy to read, but written by lakes and rivers upon a scratched and mutilated continental surface, it forms a palimpsest very difficult to decipher by the aid of stratigraphy alone. As an evidence of the truth of this statement I desire to call attention to the different views prevailing among geologists as to the age of the low level deposits known as the Port Hudson group. Some consider this as the oldest of southern Pleistocene formations, others believe that it corresponds to the last epoch of glaciation. With this formation, however, the present paper does not deal, since these deposits are not to be found within the area under discussion. Loess has not been found, I believe, in the North corresponding to the Drift of the third Glacial epoch, yet it does not follow that the Mississippi did not continue to bring down drift material during this time which may have been added to previous deposits of loess or loam.

Nor can we say that this process may not have continued for some time after the final retreat of the ice beyond the Canadian line. If we consider that the Glacial period began in the United States when the land ice from Canada first crossed the

Archæan highlands between Canada and the United States, eroding in some places and in others depositing till; and if the final retreat of the same ice mass beyond the same highlands be considered as marking the close of the Glacial period, how shall we fix the limits of a formation in the south derived largely from glacial débris? Such deposits, no doubt, are still forming to some extent near the edge of the drift-covered area; and the deposit of till in the North must have begun in advance of the deposition of the Loess-Loam, and of the Natchez formation.

We may only say that the Loess-Loam in this region is homotaxial with the drift, that being composed largely of drift materials it cannot antedate the latter and that the two were in a general sense synchronous.

C. *Conditions under which the formation was deposited.*— For a discussion of the conditions under which the Loess-Loam was deposited the reader is referred to *12th Ann. Rep. U. S. Geol. Surv.*, pp. 401–404.

This formation is to be considered as being essentially a flood-plain deposit of glacial débris (worked over to some extent perhaps by the wind), and formed during a period of subsidence, when the whole surface of the country in this region was practically at sea level. The submergence of the surface seems to have been so slight that fresh-water conditions prevailed over marine, and currents laden with glacial débris ran far southward into a tideless bay. Indications, however, of brackish, or of marine conditions, are to be found in the present "salt-licks" which occur quite frequently in the Yellow Loam of some localities, such as Tate and Panola counties.

In the absence of shore lines to mark this incursion of the sea, evidence of submergence is to be found in the areal and vertical distribution of the formation, which no other causes seem competent to explain. Still more direct evidence is afforded by the presence in some localities of huge foreign bowlders imbedded in, or at the base of, the Yellow Loam, and which, it seems, could only have reached their present positions by iceberg action, or through some supernatural agency. A

very interesting deposit of siliceous sandstone blocks is found at Rockyford, Union county, Mississippi, twenty-two miles east of Oxford. Along the hills on either side of Tallahatchie River, near the village, blocks of hard white or gray sandstone either rest directly upon the soil (the prevailing position), or are loosely imbedded in sand. Some of these bowlders will weigh, perhaps, 300 or 400 tons, and many of them present square cut surfaces as if just plucked from some parent ledge. These extend for about one-half mile only on each side of the river. The nearest bed rock at all like these blocks is a Sub-Carboniferous sandstone found in southern Tishomingo county some fifty or sixty miles distant and across the Tallahatchie-Tombigbee divide, on the headwaters of the latter. These bowlders must have been brought down by icebergs from the north, or possibly from the northeast, coming down the Tennessee River valley and across the divide between this and the Tallahatchie, into the latter, where they deposited their load by melting or by overturning.

A smaller block of angular fossiliferous chert, weighing 150 or 200 pounds, was found at the juncture of the Lafayette and the Yellow Loam at a point about seven miles east of Senatobia, in Tate county.

Similar bowlders are reported from other parts of the State, but with these I am not personally familiar.

Absence of stratification in the Yellow Loam may be due in part to its deposition from sluggish currents overloaded with fine detritus (see "Conditions of Sedimentary Deposition," JOUR. GEOL., Vol. I), but the subsequent alteration of the deposit seems generally to have been great enough to have destroyed all traces of stratification which may have existed.

D. *Subsequent alteration.*—In the study of this formation it seems to me that the idea of great chemical alteration subsequent to deposition has not been properly stressed. The fact is evidenced by the present decayed appearance of the loam proper, and by the surface alteration of the loess; by the segregation of part of the lime and iron in the former into "buckshot"

and in the latter into calcareous and ferruginous nodules. At the contact plane of the former with older formations — the Lafayette around Oxford, or the Northern Lignitic a few miles east — there are frequently selvedges of "hardpan," or ferruginous sandstone, sometimes of considerable size, and occasionally containing a high percentage of iron. These are not to be confounded with similar "iron ores" of the Lafayette. That the loess has suffered less alteration than the loam is evident. The present difference between the two may be due partly to original difference in chemical composition and physical texture, but more largely I think to a difference in degree in subsequent alteration. The latter may be attributed to the difference in thickness of the two, which would both give to the loam a higher percentage of organic matter (derived from older soils), which on decomposition would furnish abundant solvent for its soluble constituents, and also allow a freer circulation of water for the accomplishment of the decomposition of putrescible matter and consequent leaching of the loam.

The roots of existing plants, too, may penetrate through the loam as they could not always the loess. But the Memphis sections would seem to indicate, also, original local differences in chemical composition and physical texture.

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CLASSIFICATION OF THE MISSISSIPPIAN SERIES.

BECAUSE of its vast array of finely preserved fossil forms, the Mississippian or Lower Carboniferous limestone series, has, since the beginning of geologic investigation in the Mississippi valley, aroused great interest. At an early date the fossils of the successive beds were studied, and were illustrated in the geological reports of Iowa, Illinois, and Missouri, and formation names were given to the various strata. In the final adjustment of the work of all the earlier investigators, the following formation names, from the base upward, came to be recognized, (1) Kinderhook, (2) Burlington, (3) Keokuk, (4) Warsaw, (5) St. Louis, and (6) Kaskaskia or Chester. Each one of these divisions was held to be of equal importance with all the others, essentially, and until recently this original, more or less artificial, classification remained in vogue.

The true classification of rock strata and fossil faunas is but an incident in the elaboration of the geologic history of a region, and in order to make a natural classification of these phenomena, they must be considered from a historical standpoint. The classifications of rock strata which have been generally used, are based upon two distinct sets of criteria, (1) stratigraphic, and (2) faunal. A stratigraphic classification by no means excludes the fossil evidence, and is based fully as much upon the differences observed among the fossil species of successive formations as upon the physical characteristics of the strata; but the fossils are looked upon in the same light as the physical characters, as a sort of label of the strata, rather than as a real life element subject to all the laws of organisms. The old classification of the Mississippian series into the six formations indicated above was purely stratigraphic in its nature, although great stress was laid upon the fossil contents of the various formations.

It is a universally recognized fact today, that assemblages of organisms are intimately related to the environment in which they live. With a change in the environment there will be changes among the associated organisms.

In no geologic province, such as the continental interior of North America during Carboniferous time, whose history must be considered as a unit, are the physical conditions of the whole area identical at any given time. Neither are the conditions of any one limited portion of the province, identical throughout an entire epoch or chapter in its history. Local changes in the physical conditions, and consequently in the local assemblages of organisms are continually in progress. A stratigraphic classification of rock strata is based upon these local changes in the sediments and their contained organic remains, and consequently can be of but local significance. In such a classification the profound physical changes which affect the whole geologic province in its relations with adjacent provinces, are given no greater importance than the comparatively insignificant local changes.

A natural classification of strata must be a faunal classification in its broadest sense. It is based not merely upon the identity or lack of identity of fossil species in the different local formations, but upon the minute study of the relationships of the assemblages of fossils in the successive zones of particular sections, and upon the study of the geographic distribution of species. All fossil species are either indigenous or exotic to the geologic province in which they are found preserved. They are either evolution species or immigration species, and the sudden appearance of exotic or immigration species in the fauna of a geologic province, shows, as nothing else can show, that the relationship between the province and its neighbors is undergoing a readjustment. In the history of any geologic province the distinct epochs or chapters must be limited by these periods of readjustment. Oftentimes these periods cover a considerable lapse of time and alternate with periods of quiet, in which case the periods of change and the periods of quiet are most naturally considered as distinct epochs.

A name applied to a historical epoch of a geologic province, is applicable as a stratigraphic name to all the strata deposited during that epoch. It may not always be possible to draw a sharp and fixed line in the stratigraphic series between two succeeding epochs, so that everywhere, throughout the geologic province the exact limits of the historical epochs may be pointed out. It is not necessary, for the establishment of an epoch name, to select, as the type, a section in which every stratigraphic and faunal phase of the epoch is illustrated. As a matter of fact it would be almost impossible to find a type section for most geologic epochs in which all its varied phases were exhibited. It is only necessary, in the selection of a geographic name for a geologic epoch, that some one or more phases of strata and fauna be well illustrated there.

In recent years, two classifications of the Mississippian series have been proposed. The first by Williams[1] is a natural faunal classification, while the second by Keyes[2] is a stratigraphic classification which is nothing more than a further elaboration of Hall's earlier one, uniting some of his divisions and dividing others.

Williams was the first to recognize in the strata and fossil faunas of the Mississippian series, the evidence of three distinct chapters in the history of the continental interior during lower Carboniferous time, and for these chapters or epochs he used the names (1) Chouteau, (2) Osage, and (3) Ste. Genevieve. The commonly recognized local geologic formations were placed, as accurately as was possible at that time, in their respective epochs, and further investigation seems to necessitate no different disposition of them. Of the three epoch names proposed, Osage and Ste. Genevieve were used for the first time. Chouteau, on the other hand, had long been used as a formation name for one of the local limestone strata in Missouri. The Chouteau group was made by Williams to include, beside the Chouteau limestone,

[1] Bull. U. S. G. S., No. 80, p. 169.

[2] Bull. Geol. Surv. A., Vol. III, p. 283; Iowa Geol. Surv., I, p. 50; and Missouri Geol. Surv., IV, p. 76.

several other local formations, and as the relationship between the faunas of these formations had previously been recognized, and the name Kinderhook applied to them all, it seems best to use the latter name instead of Chouteau for the first epoch.

In order to have a right understanding of the history of the continental interior during Mississippian time, it will be necessary to glance briefly at the events immediately preceding During the greater part of Devonian time, the eastern interior region of North America was occupied by the great Mediterranean Appalachian sea. This sea extended from the Laurentian land on the north to the western extension of the Appalachian land[1] on the south, and from the Appalachian on the east to the Missouri land on the west. The outlines of this sea were continually changing during Devonian time, and at intervals it was joined by open passages in different directions with the outer oceans. Near the close of the Hamilton epoch, a passage through the northwestern portion of North America was opened, by means of which communication was established between the Appalachian sea, and the Eurasian ocean. This northwest passage crossed northern Missouri, Iowa, and southwestern Minnesota, and extended northward through Manitoba and the Mackenzie Valley. The Chemung fauna of the Appalachian province contains an important element derived from the European faunas, an element which without doubt found its way into the Appalachian sea through this northwest passage.

Just before the opening of Mississippian time, the distribution of land and water in North America was about as indicated in Fig. A, the northwest passage being connected with the Eurasian province. The progress of events during the period was, first, an epoch of disturbance, of readjustment and sinking land; second, a long epoch of quiet and equilibrium, with widespread marine conditions; and third, another epoch of disturbance with further readjustment between the interior province and its neighbors. These three epochs are: the Kinderhook, Osage and Ste. Genevieve.

[1] Proc. Bost. Soc. Nat. Hist., XXVI, p. 474; and A. J. S. (4), IV, p. 357.

The stratigraphic elements included in the Kinderhook group are varied in their physical characteristics. There are limestone, sandstone and shale formations. The formations are local in their distribution and characters, and consequently the different minor assemblages of organisms preserved in the strata

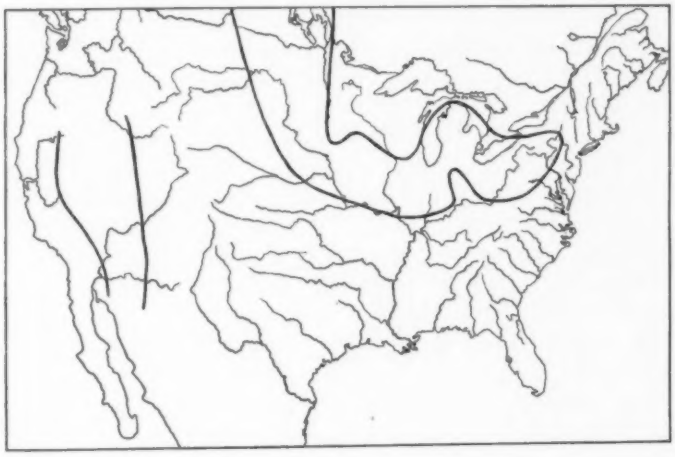

FIG. A.

are more or less local in their distribution. The Kinderkook fauna as a whole is known only in a very general way, no detailed investigation of it has ever been attempted. It is in many respects related to the Devonian faunas, and especially to that fauna which had found its way into the region from the northwest.

During the progress of the Kinderhook epoch the land was sinking to the south, and the southern shore line was migrating in that direction. The margins of the successively younger sediments transgressed further and further to the south over the ancient land surface. In central Missouri, strata of late Devonian age rest directly upon the old Ordovician land surface. In southern Missouri, strata of Kinderhook age occupy the same

position, and in central Arkansas, in the region of the Ouchita uplift, the whole Mississippian series is absent, strata of Lower Coal Measure age resting upon the Ordovician beds.

The Kinderhook epoch of generally disturbed conditions, the epoch of readjustment, was followed by the Osage which was a

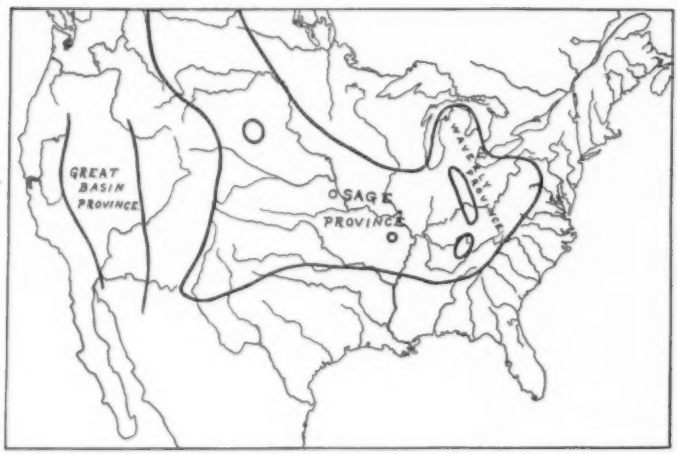

FIG. B.

long period of tranquillity. No longer were there sediments of various sorts being deposited in the interior sea. The surrounding land had sunk so low that practically no sediments were transported by the streams, and the only rock-making material furnished was the calcareous secretions of organisms. Crinoidal fragments constitute the major portion of this limestone, though the remains of corals and brachiopods are also abundant.

The probable distribution of land and water during Osage time is indicated in Fig. B. A great, quiet, interior sea extended from the Cincinnati island on the east to the Rocky Mountain land on the west, and from the southern Appalachian land to the Wisconsin land at the north. The northwest passage still furnished a means of communication with European waters.

The Osage is the best known of any of the Mississippian aunas. Hundreds of species of crinoids founded upon the most perfectly preserved specimens in the world have been described from these strata. Next in importance to the crinoids are the brachiopods, represented by many species. Besides these the corals and bryozoa are often abundant, but the remaining classes of organisms are relatively inconspicuous. The fauna has been most studied in Iowa, Illinois, and Missouri, but a good, crinoidal, Osage fauna has been described from southwestern New Mexico,[1] and crinoids certainly indicating the presence of the fauna have been described from near Bozeman Mountain.[2]

The Osage fauna has many points of resemblance with the fauna of the mountain limestone of western Europe. In each there is a large crinoidal and a large brachiopod element. Every genus of crinoids in the European fauna is represented in the American, and many species of brachiopods are common to both regions, though the American specimens have sometimes been given different names. The following is a partial list of identical or representative brachiopods in the two regions:

American species	European species
Athyris increassatas H.	*Athyris roissyi* L'Eveille.
A. lamellosa L'Eveille	*A. lamellosa* L'Eveille.
Camarophoria subtrigona M. and W.	*Camarophoria isorhyncha* McCoy.
Chonetes illinoiensis Worthen.	*Chonetes hardrensis* Phill.
Dielasma hastata Sow.	*Dielasma hastata* Sow.
Dielasma sacculus Martin.	*Dielasma sacculus* Martin.
Leptæna rhomboidalis Wilck.	*Leptæna analoga* Phill.
Orthis (Rhipidomella) burlingtonensis H.	*Orthis michelini* L'Eveille.
O. (Schizophoria) swallovi H.	*O. resupinata* Martin.
Productus laevicostus White.	*Productus cora* D'Arb.
P. punctatus S. Martin.	*P. punctatus* Martin,
P. burlingtonensis H.	*P. semireticulatus* Martin.
Rhynchonella pleurodon Phill,	*Rhynchonella pleurodon* Phill.
Spirifer grimesi H.) *S. Logani* H.)	*Spirifer striatus* Martin.

[1] A. J. S. (3), XXVII, p. 97.

[2] Bull. Ill. State Mus. Nat. Hist., Nos. 10 and 12.

American species.	European species.
S. lineatus Martin. *S. lineatoides* Swall. *S. pseudolineatus* H.	*S. lineatus* Martin.
S. suborbicularis H.	*S. ovalis* Phill.
S. tenuimarginatus H.	*S. duplicicostus* Phill.
Syringothyris carteri H.	*Syringothyris cuspidatus* Martin.

The similarity between the faunas of the two regions is so great that some way of intercommunication must have been in existence. The presence in Grinnell Land[1] of a similar fauna, in some respects intermediate between the two, would seem to indicate a northern and then eastern passage-way between the interior American province and western Europe.

The physical changes, which initiated the interior continental province of Osage time, were of a different nature from the changes that had ushered in previous epochs in the history of the region; and as a consequence, the fauna of the Osage epoch falls into a different category from earlier ones. In no case were the changing faunas of the Appalachian province during Devonian time, to any great extent, indigenous in their origin. The Osage fauna, however, was apparently very largely native to the region. The western European faunas doubtless exercised their influence upon it, but the influence of the American fauna upon that of Europe seems to have been much the greater.

A large portion of the territory occupied by the Osage province had previously been dry land. A vast area of new sea bottom was formed by the sinking of the land. The marine organisms which were to inhabit the region were unhindered in their development. They came in contact with no previously existing fauna which had either to be driven out or to be absorbed into their own social organization. Their rapid growth and differentiation may be compared with the rapid development of a human civilization in a newly opened country with vast resources, where there is a place for everyone with strength and vigor, and where the close struggle of individual with individual does not

[1] Q. J. G. S. Lond., XXXIV, p. 568.

exhaust the vitality. While the close struggle for existence between individuals does seem to be a means of bringing about many minor differentiations of specific importance, the more important differentiations of generic or higher rank seem to be associated with conditions under which there is a wealth of resources, where the struggle is between the organism and the physical environment to a greater extent than between organisms and their nearly related fellows.

The characteristic features of the Osage fauna were assumed at its beginning. After this the struggle was to a greater extent between individuals, and the organic changes were of minor importance, being to a great extent of no more than specific rank.

That the influence exerted by the American fauna upon that of western Europe was greater than the influence of the European upon the American fauna, is shown by a comparison of the crinoidal elements of the faunas in the two regions. In the Osage faunas of America 50 genera of crinoids are recognized, and in the equivalent faunas of western Europe 21 genera. Of the European genera not a single one is peculiar to the region, each being also represented in America. On the other hand 29 genera are peculiar to the American fauna. Furthermore, of the genera which occur both in America and in Europe, a larger number of species are known in America than in Europe. These facts seem to show that as between the two the point of origin or of major distribution of this crinoidal fauna was in the continental interior province of America, and that in the course of its existence it probably migrated from this province into other regions.

During the time when the broad expanse of the clear waters of the Osage sea was the most conspicuous feature of North America, there were in existence at least two other and smaller geologic provinces in which different physical conditions prevailed, and which were inhabited by very different assemblages of organisms. The first of these, the Waverly, lay to the east of the Osage province, between the Cincinnati island and the

Appalachian land, and extended from Michigan through eastern Ohio and western Pennsylvania south to the Ohio River. There was direct communication between this and the western Osage province, and during the Kinderhook epoch there was a considerable community of faunas, but at no time did the clear water conditions of the Osage sea extend into the Waverly gulf. Consequently the clear water Osage species did not generally flourish in the Waverly province, though enough have been recognized to show that the Waverly series is practically the equivalent of the formations of the Kinderhook and Osage epochs combined.

While the interior of the continent was sinking and the Osage sea was spreading out towards the Rocky Mountain land, the land on the northeastern border remained well above sea level. Under these conditions abundant clastic sediments were continuously furnished to the northeastern Waverly gulf, but the long Cincinnati island extending north and south across its mouth prevented the spreading of the sediments into the clear waters of the Osage sea beyond.

In the western part of the North American continent, lying between the Rocky Mountain land on the east and the Californian land on the west, was the Great Basin province. In this province there had been no important change in the passage from Devonian to Carboniferous time. While in the interior of the continent there was but a short interval, the Kinderhook epoch, during which an apparent mingling of Devonian and Carboniferous species is observed, in the Great Basin province Devonian species continued to live, associated with others of Carboniferous types, long after they had disappeared in the Osage province.

Following the prolonged quiet of the Osage epoch in the interior, there was another long period of readjustment and change, which culminated in the elevation of the greater part of the region previous to the deposition of the widespread millstone grit formation which initiated the Coal Measures. This was the Ste. Genevieve epoch. In the far west the barrier

between the Great Basin and the interior provinces was submerged, allowing the incursion of the Great Basin fauna with its persistent Devonian species into the interior. This recurrent Devonian element in the faunas of the interior, first definitely recognized in the Spring Creek limestone from near Batesville, Ark.,[1] is the faunal mark of the initiation of a new chapter in the geologic history of the continental interior. This element is characteristic of the St. Louis fauna wherever it exists. One of the best known of the St. Louis limestone faunas is that of the Spergen Hill beds in Indiana, and in this fauna the recurrent Devonian element is recognizable in the species of *Microdon*, *Conocardium* and *Nuculana*, genera which had disappeared from the interior of the continent during the Osage epoch. Although the Spring Creek and Spergen Hill faunas are quite different in many minor details, they possess many species in common, showing their relationship. In addition to this resemblance of the Spergen Hill fauna to the Spring Creek fauna, which is closely allied to the Great Basin fauna, a fauna practically identical with that of the Spergen Hill beds has been recorded from the far northwest in Idaho,[2] an occurrence which suggests the possibility of its immigration into the interior from that direction.

During the latter part of the Osage epoch there was apparently an emergence of the northern shore line in the region of Iowa, because the younger beds of the Osage group do not extend so far north as the older ones. With the beginning of the Ste. Genevieve epoch, however, this was all submerged again, and the St. Louis limestone strata extended farther to the north than the immediately preceding ones. This submergence was followed by a considerable reëlevation at the north, the Kaskaskia beds being deposited only in the southern portion of the province. The successive changes, more or less abrupt, in the sediments of the Ste. Genevieve group from limestone to sandstone, to shale and back again to limestone, etc., indicate

[1] Am. Jour. Sci., XLIX, p. 94.

[2] A. J. S. (3), V, p. 383.

that rapid and relatively violent local changes were in progress throughout this whole period of readjustment.

The fauna of the Ste. Genevieve epoch in all its varied phases is but imperfectly known, but it apparently contains, throughout, in greater or less degree, the western element suggestive of the prolonged Devonian, which first makes its appearance in the St. Louis limestone fauna, and continues on even into the faunas of the Coal Measures.

In the geologic history of our continent during Mississippian time, many details remain to be elaborated, and with the elaboration of these details our conception of it may be altered in some respects. It is believed, however, that further investigation will but make clearer the general features as outlined here. The threefold classification of the Mississippian strata, based upon the actual geologic history of the region as told by the fossils and by the geographic evolution, is seemingly the only natural one.

An attempt has recently been made[1] to substitute the name Augusta for Osage. The two names have been proposed for practically the same stratigraphic series, but in their proposal the two authors seem to hold very different conceptions of the criteria which should be used when the classification rises above the mere grouping of beds of a local character. The name Osage was proposed for a definitely recognized chapter in the geologic history of the region under consideration, while Augusta was proposed as the name of a special stratigraphic division composed of certain local formations. Hair-splitting distinctions between the exact limitations of groups of beds—however necessary in local and minor classifications—can have no decisive weight in the case, when the higher purpose of major classification, as an expression of the vital features of the history of the region, are duly considered.

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[1] Am. Geol., XXI, p. 229.

EDITORIAL.

AMONG the incidental effects of the war between the United States and Spain will be an awakening to geographic and geologic relations. Even while war was but an anticipation there was not a little brushing up of rusty geography. Now that it is on the study will begin in earnest. And there is need of it. Not a few prognoses of the coming campaign, gravely announced and seriously discussed by the press correspondent, or the public functionary, or the club oracle, have been little less than absurd through their neglect of geographic relationships. Among the masses, and even among people of education, forecasts of quite possible eventualities of the war have been commingled with imagined eventualities which geographic relations altogether prohibit. Even to those fairly well informed the awakenings of the war will bring the rectification of many a false impression and not a little accession of fresh geographic knowledge. Just at this moment when one Spanish fleet is reported to have left Cadiz and another St. Vincent, and their destination is a matter of intense solicitude, it will perhaps come as a revelation to most of us that the Cape Verde Islands are nearer Boston than is Cadiz; that they are nearer Maine than Cuba; that St. Vincent is less distant from every American port on the Atlantic coast than it is from Havana. Both Spanish fleets when they set sail (if indeed they did) were nearer all our Atlantic ports than they were to Admiral Sampson's fleet.

There is, therefore, ample occasion for brushing the dust from our atlases and for the application of rule and compass to them with due regard to the mode of map projection. Beyond question the people of this republic will very generally become better instructed in the geography of the north-central

Atlantic and the north Pacific. They will take a new lesson in geography under the impulse of a grewsome interest and a solicitous intensity not equaled since the early sixties. And the public press with all its faults and errors will become one of the most effective teachers.

But even recourse to the best atlases will leave room for the rectification of erroneous impressions unless used with a circumspection not often realized. Recourse to the globe is to be urgently recommended. Every household which seeks to surround itself with convenient means for promoting an accurate intelligence of the great historical events of the passing days may well provide its living room with a globe — not necessarily large or expensive, for six-inch globes of fair accuracy and detail are in the market at seventy-five cents apiece. Institutions would do well to buy these by the dozen and use them for all sorts of diagrammatic purposes. The globular presentment is the true presentment of the earth ; the map is its false presentment in more than a rhetorical sense.

To some extent public interest will extend to geologic factors. The distribution of coal is confessedly a pivotal element in the contest and the natural sources of coal, as well as its commercial distribution, will become familiar to thousands to whom such facts, under conditions of peace, would appeal only with indifference. The special configurations of the American and Spanish coasts are certain to be studied with peculiar intensity. The phenomena of sunken channels, of inlets and harbors, of spits and bars, of reliefs of the land and like features of military significance, will all take on an intensity of interest correspondent to the great issues which may hang upon the aid or the hindrance these features may give in the determination of results.

The actual contact with geographic and geologic phenomena into which the hundred thousand young men, more or less, will be brought as the result of the impending campaign will be to them, and through them to others, a geographic education of no little moment. It was observed at the close of the Civil War

that those who returned from its campaigns possessed an appreciation of the elements of position and physical relationship quite beyond that realized by the preceding generation educated under the benign influences of peace.

These incidental contributions to our favorite sciences and to those elements of education that are associated with them will be among the compensations to be set over against the calamity of war. T. C. C.

Reviews.

PROFESSOR SPRING ON THE PHYSICS AND CHEMISTRY OF SOLIDS.

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The prime importance to the geologist of all investigations upon the relations of matter and force at great temperatures and pressures makes it profitable, perhaps, to review the work of Walther Spring on this subject. Professor Spring is the pioneer in this field. All his conclusions and theories on the chemistry and mechanics of solid bodies are founded upon a long series of careful experiments, in the course of which he has kept substances under great pressure for periods of more than twenty years, and these furnish us almost the only trustworthy information we have on the subject. It is of especial importance to call the attention of American geologists to this work of Professor Spring, as some discredit was thrown upon his work by M. W. Hallock in a contribution published in *Bulletin 55* U. S. Geol. Survey called "The Flow of Solids, or the Behavior of Solids Under High Pressure." The critic fell into an error through a mistranslation or a misapprehension of the French language,[1] especially translating "se souder" as to melt, and through his failure to grasp the fact that there may be a molecular diffusion in substances in the solid state.

Professor Spring's development of the subject was gradual and followed the advance of his experiments, so that a chronological review of his papers will give us a good exposition of his theories. In his first paper,[2] which was preliminary, he raises the question how sedimentaries harden where there has evidently been no cementation. He states that he has been able to press perfectly dry K NO_3 and Na NO_3 under a pressure of about 20,000 atmospheres into semicrystalline masses harder than the fused substances. Two years later he contributed his first important paper on the subject,[3] which contains,

[1] Simple observation au sujet d'un travail de M. W. Hallock intitulé: "The Flow of Solids," etc. Bull. de L'Académie Royale de Belgique. 3^{me} série, 45, 1887, p. 595.

[2] Note préliminaire sur la propriété les fragments des corps solides de se souder par l'action de la pression. Bull. de L'Académie Royale de Belgique. 2^{me} série, 45, 1878, p. 746.

[3] Sur la propriété que possèdent les corps solides de se souder par l'action de

besides his own valuable results, an excellent résumé of all the different theories concerning regelation. From experiments upon all kinds of chemical compounds he develops the following:

1. All solid bodies tend to consolidate under pressure, and this tendency is a function of the malleability of the substance or, in other words, an inverse function of the internal friction.

2. Pressure aids in consolidating or welding solid bodies because it makes an intimate contact.

3. Bodies capable of assuming crystalline form tend, under pressure, to weld so that the mass has a single crystallographic orientation.

4. Welding under pressure is caused by an actual molecular diffusion in the solid state similar to that in liquids, but far less active.

5. Pressure aids diffusion merely by bringing the particles into intimate contact with each other.

6. The reactions of solids upon solids are equilibrium reactions, and therefore chemical action under pressure tends to go in the direction which gives the smaller volume. Therefore, since the crystalline state is generally that which takes the smallest volume, pressure aids crystallization.

In two succeeding articles he states that solids, as well as liquids[1] and gases, are perfectly elastic volumetrically, that is, upon removal of pressure, the molecules vibrate with the same frequency as before and so the substance assumes its former volume. The only compression he could produce was caused by the crushing in of cavities, etc., and large contraction only occurred where new chemical compounds were formed, as where a new allotropic or polymeric form of the substance was assumed. The statement that matter takes an allotropic state corresponding to the volume which it is obliged to occupy has an exact significance. Moreover, the different states of matter all belong to one series—a liquid is an allotropic form of a gas—a solid of a liquid—a denser solid of a solid of less specific gravity.

This polymerization of molecules accounts for all changes of form and the more dense the polymeric forms, in every case the less active

la pression. Bulletins de l'Académie Royale de Belgique. 2^{me} série, 49, 1880, p. 323.

[1] Formation de sulphures métalliques sous l'action de la pression. 3^{me} série, 5, 1883, p. 492.

Sur l'élasticité parfaite des corps solides chimiquement définis. Analogie nouvelle entre les solides, les liquides et les gaz. 3^{me} série, 6, 1883, p. 507.

are they chemically. This last fact may partially explain the occurrence of chemically active substances uncombined deep within the earth. It is to be noted, however, that temperature acts in an opposite sense to pressure and for every allotropic state there may be a critical temperature above which it cannot exist no matter under what pressure.

In several following papers he explains experiments which confirm his previous conclusions on the diffusion of matter in the solid state. He finds that the velocity of diffusion depends upon three factors: (1) a constant peculiar to each substance and depending upon the velocity of molecular movements; (2) the temperature, with which the molecular velocity increases, and (3) the pressure, which makes the contact more perfect and tends to overcome the "surface tension" of the solid particles. He demonstrates that there is a critical temperature for the change of solids into liquids and mentions cases where liquids by increase of pressure have been changed into solids.[1]

In further experiments he finds that intimate contact caused by constant shaking without pressure causes diffusion between solids, and this diffusion takes place with extraordinary rapidity (three hours) at a higher temperature, though far below the melting point of either substance employed.[2]

In the article "Sur l'apparition dans l'état solide des certaines propriétés caractéristiques de l'état liquide ou gazeux des métaux,"[3] he recapitulates some of his former conclusions and presents new ones as follows:

1. Cohesion between fragments like that between drops of water must be overcome before diffusion between the two can take place.

2. The property of diffusion under pressure is not equally developed in all bodies and is best developed where internal friction is the least and where molecular velocity is the greatest.

[1] Réaction du sulfate de baryum et du carbonate de sodium sous l'influence de la pression. Bull. de l'Académie, etc. 3^{me} série, 10, 1885, p. 204.
Bull. de la Société chimique de Paris, XLI, p. 488.
Sur un case de décomposition chimique produite par la pression. Bull. de 'Académie, etc. 3^{me} série, 13, 1887, p. 409.
Zeits. f. Phys. Chemie. I, p. 165.
Comptes rendus, t. CV, 1887, p. 165.

[2] Sur la réaction chimique des corps à l'état solide. 3^{me} série, 16, 1888, p. 43.

[3] Bull. de l'Académie, etc. 3^{me} série, 28, 1894, p. 23.
Zeit. f. Phys. Chemie.

3. Pressure alone is not so efficient as when accompanied by an agitation of the particles which breaks their cohesion and aids diffusion. This explains cold welding, etc.

4. The three states of matter are only extreme degrees of a single ne and each has a critical pressure and temperature. Solids as well as gases and liquids have faster and slower moving molecules and this variation is the most extreme where the free path is the greatest, viz., at the surface, and therefore solid bodies in contact will weld at their surfaces when below the melting point, due to the interaction of the "liquid molecules."

5. The molecular mobility of a solid body is a function of the proportion of the rapidly moving portion (liquid molecules) to the whole number of molecules.

6. Crystalline bodies have a nearly uniform rate of molecular vibration, and therefore do not "solder" at a temperature much below melting, while amorphous or partially crystalline bodies with heterogeneous molecular motions weld easily.

Finally, in the contributions of the last few years[1] he has described some of his most remarkable experiments on this subject which confirm all his former conclusions. He kept perfectly dry powdered chalk under a pressure of from 6000 to 7000 atmospheres for seventeen years and three months. This same pressure acting through a short time only makes the chalk about as hard as ordinary writing crayon, but after this long time it was found as hard as marble. The fracture was conchoidal and the microscope showed it was crystalline. The steel screw which held the chalk under pressure had completely united to the cylinder, so that the cylinder had to be cut. The chalk was of a yellow ochre color to the depth of $1\frac{1}{2}^{mm}$, showing that the iron molecules had diffused $1\frac{1}{2}^{mm}$ into the chalk in about seventeen years.

This diffusion was at the ordinary temperature, but he has shown that at higher temperatures the velocity is much greater and "not only tends to complete the homogeneity of the solid solution, but also to cause an orientation of its molecules." These observations he applies as follows: "Les faits que j'ai observé contribueront peut-être à jeter

[1] Bull. de l'Académie, etc., 3^{me} série, 1895. De l'influence du temps sur l'agglutination de la craie comprimée.

Sur les modifications physiques que subissent certains sulfures sous l'influence de la température. Bull. de l'Académie, 3^{me} série, 1895, p. 311.

Zeit. f. Phys. Chem.

quelque lumière sur la question de la solidification des roches dans la nature. Ils peuvent nous faire comprendre pourquoi, en général, les roches les plus solides et les plus compactes sont aussi les plus anciennes, et ils peuvent nous expliquer la présence de ces milliards de cristaux microscopiques que l'on a observés dans certaines roches, par exemple dans les phyllades, cristaux qui paraissent s'être développés même après le dépôt des alluvions nécessaires à la formation de ces masses neptuiennes."

And again: "Cette observation ne me paraît pas sans conséquence pour certaines théories pétrographiques. En effet, s'il est déja possible d'observer un changement d'état physique dans un agglomérat après onze années d'exposition à la température ordinaire, il est permis de penser que nombre de phénomènes de crystallization, voire de formation de numéraux, dans les roches agglomerées par la pression, aux dépens de matières à l'état solide, sans qu'il soit absolument nécessaire de faire entrevenir l'action de dissolvants quelconques."

He has also[1] experimented with the compression of dampened powders and finds in general that the insoluble bodies, such as metal filings, etc., do not solidify in the presence of water because the water prevents close contact. Soluble substances act differently — bodies whose solution takes less volume than the water and substance solidify more completely than in the dry state, while those whose solution is attended with an expansion of volume consolidate much better in the dry state. The explanation offered is that when the substance is more soluble under pressure, as pressure is relieved some of the material is precipitated into the interstices of the mass and it is solidified, while in the second case some of the matter is dissolved after the relief of the pressure, leaving a porous incoherent mass.

M. Le Chattilier[2] has noted this same fact that certain bodies in the presence of their saturated solutions solidify under pressure, and explains it a little more in detail as a case of equilibrium under heterogeneous pressure. The water is squeezed out of the mass and therefore is not under so great a pressure as the solid, therefore the solution next to the surface of the solid is supersaturated in respect to that farther away. This water then moving away from the solid precipitates and solidifies the rock.

[1] Zeits. für Phys. Chem., 2, p. 532. Über die Kompression von feuchter Pulver fester Körper und die Formbildung der Gesteine.

[2] Zeits. für Phys. Chem., IX, p. 335.

It has long been known that rocks suffer actual molecular movement if the forces act so slowly that they do not overpass the elastic limit of the rock, and again bodily movement must take place if the rock is subject to stresses greater than the ultimate strength of the rock, but the knowledge of the fact that solid matter has so much in common with gases and liquids is almost wholly due to the laborious investigations of Professor Spring, and these facts should immediately take their place in our theories of the condition of matter in the interior of the earth. C. F. TOLMAN, JR.

United States Geologic Atlas, Folio 37. Downieville, California. 1897.

This folio consists of eight pages of text signed by H. W. Turner, geologist, a topographic map of the district, a map showing the areal geology, a map showing the economic features, a structure section sheet, and one page of special illustrations.

The quadrangle represented in this folio lies between parallels 39° 30′ and 40° north latitude, and 121° and 120° 30′ west longitude. It comprises a portion of the northern Sierra Nevada and lies in Plumas and Sierra counties. The area is drained by the forks of the Feather and Yuba rivers.

The formations are divided into two main groups, the bed-rock series and the superjacent series. The bed-rock series is composed of Juratrias and Palæozoic sediments and tuffs, and a series of old igneous rocks chiefly granites and porphyries. The Juratrias rocks comprise chiefly the Milton formation which is found only in the southeast portion of the quadrangle. The Milton formation, while formed of materials deposited under water, contains a large amount of igneous material. Underlying the Milton formation there are volcanic beds which are likewise presumed to be of Juratrias age, inasmuch as in the lower portion there are lenses of siliceous argillite, in one of which an ammonite was found. These volcanic beds are grouped as quartz-porphyry and as augite-porphyrite. The quartz-porphyry also occurs as dikes. The other igneous rocks forming part of the bed-rock series are granite, gabbro, and granodiorite. In the western portion of the quadrangle there are very large amounts of serpentine which have resulted from the decomposition of the pyroxene olivine rocks or peridotites and amphibolite which is the result of dynamo-metamor-

phism and hydro-metamorphism of augite-porphyrite. The rocks of the auriferous slate series comprise, besides the Milton formation just noted, an older set of rocks probably largely of Carboniferous age, as fossils of that age only have been found in them. These Carboniferous rocks are divided into two formations, the Robinson formation of late Carboniferous or possibly of Permian age, and the Calaveras formation, comprising rocks probably older than the Robinson formation.

The superjacent series consists of river slake deposits, moraines, and volcanic material. All of the rocks of the bed-rock series, both slates and igneous rocks, were greatly eroded during Cretaceous time and upon this old eroded surface there has been deposited by rivers of Tertiary age an extensive series of gravels, known as the auriferous gravel series. The river system of Tertiary time appears to be divisible into two distinct drainage systems with a divide between. This divide is represented by the high ridge of which the Sierra Buttes is the culminating point. The rivers to the west of this high north-south ridge drained southerly or southwesterly in Tertiary time as they do now. The deposits to the east of this Neocene divide appear to have been deposited by one large river which flowed north, draining into a basin to the north of the quadrangle. Superimposed upon these gravels, and at other points upon the older bed-rock surface, are extensive deposits of lavas, mostly in the form of breccias which have been very largely eroded. At one time these lavas probably covered nearly the entire surface of the quadrangle. They consist chiefly of andesites and basalts. The latest basalts, notably the kind forming the larger portion of Mount Ingalls, are possibly of early Pleistocene age. After the volcanic forces had subsided, portions of the region were occupied by glacial ice, resulting in the formation of very extensive moraines, which are finely seen on the east slope of the Sierra Buttes, about Gold Lake, and in the neighborhood of Johnsville. All of the lakes that lie on the east slope of the high ridge extending from the Sierra Buttes to Eureka Peak, are of glacial origin.

There are evidences of faulting in Tertiary and later time at various places in the district. The largest fault zone is that lying immediately west of Mohawk Valley. The faulting along the south and west sides of the American Valley, may perhaps be correlated with the same fault zone. As a result of this faulting the country to the east of the fault zone has subsided, resulting in the formation of the Mohawk and American valleys. Mohawk Valley, during early Pleistocene time,

was occupied by a lake which has left terraces about the valley. These are finely preserved on the slope west of the north end of the valley.

Economic geology.— As economic features there are represented on the map numerous lenses of limestone, which is often highly magnesian. Gold quartz veins are indicated by orange dashes. The auriferous gravels are noted, and also deposits of chrome iron and of magnetite.

Bulletin of the American Museum of Natural History. Vol. IX, 1897.

This volume contains twenty-four separate articles contributed by members of the museum staff. Those from the departments of vertebrate and invertebrate palæontology will be briefly noticed.

Article IV. *Note on the Hypostome of Lichas (Terataspis) grandis* Hall. By R. P. WHITFIELD, pp. 45–46.

Lichas (Terataspis) grandis, is one of the largest and most highly ornamented trilobites of the Devoinan faunas. As yet it has never been found preserved except as fragments, and previous to the present paper no hypostome of the species has been described. This note by Professor Whitfield describes, with illustrations, two large hypostomes supposed by him to belong to this species. They are from loose bowlders of Schoharie grit obtained in northern New Jersey and are associated with other fragments of the same trilobite and with other species of the same horizon.

Article VI. *The Ganodonta and their relationship to the Edentata.* By J. L. WORTMAN, pp. 59–110.

The relationship of the Edentate mammals has long puzzled zoölogists, and previous to the establishment of the suborder *Ganodonta* by Dr. Wortman, no palæontologist has more than suggested what this relationship might be. Although the genera composing the group have long been known, yet the materials, up to the present time, have been so imperfect and fragmentary as to preclude any very exact knowledge of their affinities, and they have been placed by different authors at different times with the *Tillodontia*, the *Tæniodonta*, and the *Creodonta*. By the aid of the discovery of a fore limb of one of the species, *Pisittacotherium multifragum*, in association with the lower jaw and

upper teeth, Dr. Wortman has been enabled to interpret the somewhat fragmentary remains of the other genera and to make out what he believes to be, not only their affinities to each other, but what is still more important, to demonstrate their genetic relationship to the later appearing American *Edentata*.

The genera included in the suborder are *Conoryctes*, *Onychodectes*, *Hemiganus*, *Pisittacotherium*, *Calamodon*, and *Stylinodon*. In the treatment of the relationship of these genera to the *Edentata*, seventeen points of resemblance are enumerated, and they are considered as a primative suborder of and the ancestors of the Edentates.

The South American Edentates appear suddenly in the Santa Cruz formation in great numbers and variety with apparently no previous announcement in the older deposits. This fact would seem to indicate that they were immigrants from another region. While the Santa Cruz beds cannot yet be accurately placed in the time scale, it is highly probable that they are not older than the North American Oligocene. In North America the *Ganodonta* appear in the very earliest Puerco deposits and continue without interruption into the Bridger, where they disappear.

If Dr. Wortman's conclusions as to the relationship of the *Ganodonta* to the *Edentata* be correct, as they seem to be, the geographic distribution of the groups would suggest that during Eocene time there was at least a temporary connection between the North and South American continents, allowing the immigration from the north, of the ancestors of the South American Edentate fauna.

Article XI. *Description of New Species of Silurian Fossils from near Fort Cassin and elsewhere on Lake Champlain.* By R. P. WHITFIELD, pp. 177–184. Plates IV–V.

The fauna of the Fort Cassin beds on Lake Champlain is one of remarkable interest. Its position is in the Lower Ordovician, in the upper part of the Calciferous formation. As a rule the Calciferous strata do not furnish an abundance of fossils, either specifically or individually, but the Fort Cassin beds are an exception. Two previous papers containing descriptions of species from this bed by Professor Whitfield[1] have appeared, so that in all 60 species are now known, distributed as follows, 25 gastropoda, 17 cephalopoda, 8 trilobites, 7 brachiopoda, 2 crustacea (not trilobites) and 1 bryozoan.

[1] Bull. Am. Mus. Nat. Hist., I, p. 293, and Bull. Am. Mus. Nat. Hist., III, p. 25.

Article XII. *Descriptions of species of Rudistæ from the Cretaceous Rocks of Jamaica, W. I., Collected and Presented by Mr. F. C. Nicholas.* By. R. P. WHITFIELD, pp. 185–196. Plates VI–XXII.

This papers contains descriptions with excellent illustrations of ten new species of these interesting fossils from Jamaica. Six species are referred to the genus *Radiolites*, and four to *Caprina*.

Article XX. *Observations on the Genus Barrettia* Woodward, *with Descriptions of New Species.* By R. P. WHITFIELD, pp. 233–246. Plates XXVII–XXXIII.

The genus *Barrettia* was established by Woodward, upon some peculiar cup-shaped fossils from the Cretaceous limestone of Jamaica, W. I., and was referred by him to the *Rudistæ*. Since the original description several authors have expressed doubts as to the correct reference of the genus to this group, and have questioned its molluscan nature, considering it to be more probably a coral.

Professor Whitfield's investigation of the genus is based upon a collection of these fossils, some of them of large size, sent to the museum by Mr. F. C. Nicholas. All of the characters, some of which were not observed by Woodward, are carefully summed up and the conclusion is reached that they are most probably corals. The paper is concluded by the description of two new species.

Article XXI. *The Huerfano Lake Basin, Southern Colorado, and its Wind River and Bridger Fauna.* By H. F. OSBORN, pp. 247–258.

The presence of Eocene beds in the Huerfano River basin of southern Colorado, was first made known, in 1888, by Professor R. C. Hills, of Denver. Three papers, published between 1888 and 1891, record the results of his observations upon the region. In the course of his investigation, the Huerfano series was divided into three divisions, beginning from the top as follows, (1) Huerfano beds 3300 feet, (2) Cuchara beds, 300 feet, and (3) Poison Canyon beds 3500 feet. The Huerfano beds were correlated with the Bridger group or Middle Eocene, on the basis if the vertebrate remains discovered, and the two lower divisions were provisionally referred to the lower Eocene from their stratigraphic position, no fossils being found.

At a later date the region was visited by Professor Osborn and Dr. Wortman, and the present paper records the results of their observations.

The two lower divisions, the Cuchara and Poison Canyon beds, were found to lie unconformably below the Huerfano beds, and from the presence of a species of *Baculites* it is supposed that they are Cretaceous deposits of marine origin. These Cretaceous beds were found to be certainly not 800 feet below the summit of the upper Huerfano beds, so that the observation affects not only the determination of the age of the Poison Canyon and Cuchara beds, but materially reduces the thickness of the upper beds.

The only true Huerfano lake deposits are variegated marls, clays, soft shales and sands, aggregating only 800 to 1000 feet in thickness, and lying in a nearly horizontal position. In these beds, although without doubt forming a continuous deposition, two distinct horizons were identified from their inclosed vertebrate remains. The upper one of these horizons, the one from which Professor Hills secured the major part of his material, is of Bridger age. The lower horizon, however, contains none of the forms characteristic of the Bridger level, but is distinguished as of Wind River or of Wasatch age, by the presence of several characteristic lower Eocene forms.

Article XXII. *A Revision of the Puerco Fauna.* By W. D. MATTHEW. Pp. 259–323.

The Puerco fauna was first described by Cope in numerous papers published between 1881 and 1888. Ninety-one species of mammals were recognized, and to these three more were added by Osborn and Earle in 1895. The original collections used by Cope are now the property of the museum, and to these have been added important collections made by the museum expeditions in charge of Dr. J. L. Wortman. The present revision is based upon all of these collections, and consists largely in a rearrangement of the species and a reduction of their number, made possible by the more perfect material.

The fauna of the upper Puerco beds is found to be entirely distinct from that of the lower beds, not a single species being common to both, and in no case does a genus pass through without serious modification of at least subgeneric value. Because of this difference in the faunas, Dr. Wortman proposes to designate the upper beds by the name Torrejon formation.

The Puerco-Torrejon faunas are composed of the following elements:

1. The Mesozoic group of Multituberculates culminates in the

Puerco and dies out in the Torrejon, true Rodents coming in to take its place.

2. The main body of the fauna is composed of primitive types from which sprang the Ungulates on the one hand and the later Creodonts and Carnivores on the other. In the Puerco these two divisions are hardly distinguishable, but in the Torrejon they are clearly separable, although still closely allied.

3. A few more specialized lines, the Edentata, Amblypoda and Rodents, with a fourth type allied to the Primates, may be separated from the main group.

A total number of seventy-five species is recognized in the whole fauna. STUART WELLER.

Authors' Abstracts.

ABSTRACT OF PAPER READ AT THE MONTREAL MEETING OF THE GEOLOGICAL SOCIETY OF AMERICA.

Weathering of Alnoite in Manheim, N. Y. By. C. H. Smyth, Jr.

A somewhat altered dike of alnoite, consisting of biotite, serpentine, magnetite, perofskite, apatite, and some calcite, is exposed on the east bank of the East Canada Creek. Melilite, abundant in two neighboring dikes, is not apparent, doubtless being obscured by alteration.

On the west bank the dike is weathered to a fine yellowish-brown sandy clay, exposed about fifteen feet vertically. Under the microscope, the weathered material is seen to consist chiefly of biotite, magnetite, and perofskite, the other minerals being no longer recognizable.

From chemical analysis, it is evident that the rock in weathering has lost about 27 per cent., chiefly silica and magnesia, with less lime and potash. Alumina and titanic oxide show a relative gain in the same ratio, and are assumed to have remained constant. Iron also shows a relative gain, but slightly less than that of alumina, while it has undergone much oxidation. The amount of water has been very largely increased.

The greatest percentage of loss for a single constituent (excepting CO_2, which has totally disappeared) is shown in the case of potash, of which 92.27 per cent. has been removed. Soda has lost about 75 per cent., magnesia, 49 per cent., lime 45 per cent., silica, 27 per cent., and iron oxide less than 4 per cent.

The process of weathering has involved this considerable solution, together with oxidation and hydration. The accompanying physical changes are a complete change of color, and a disintegration so thorough that the material may be easily scooped out with the hands.

The contrast between alteration and weathering is pronounced. The former led to the formation of serpentine and calcite, without

oxidation. Weathering, on the other hand, destroyed both of these minerals and effected much oxidation. The first process could hardly be regarded as destructive, the last is eminently so.

The weathered dike occurs in the nearly vertical rock wall of the creek gorge, which is doubtless of postglacial origin. As the dike, in its present condition, would offer almost no resistance to the attack of the stream, it is evident that in the first stages of gorge cutting the rock must have been nearly or quite unweathered. From this it follows that the weathering, as now seen, has been accomplished in postglacial time.